PRODUCTION AND CHARACTERIZATION OF PRECIOUS AND RARE ELEMENT STANDARDS FOR MINERALOGICAL STUDIES

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SYNOPSIS

The calibration of the ion microprobe - or secondary ion mass spectrometer (SIMS) - for quantitative microanalysis of Pt, Rh, Pd, Ir plus Ga and Ge in a broad range of mineral matrices is discussed. Standards were produced by 1MeV ion implantation into polished coarse mineral particulates (1 - 30 mesh). Except for Pd, all other implants are 98.5% isotopically pure. The implant dose was confirmed by Rutherford Backscattering. Mineral and element specific calibration curves for external standardization were produced by depth profiling the implanted specimens. The precision of the analyses using the calibration curves is 10% at the 95% significance level. It was established that SIMS analysis of sulphide and oxide minerals is most sensitive for Pt, Ir, Rh and Ga and less sensitive for Pd and Ge. Minimum detection limits (3σ) for Pt, Ir, Rh and Ga are of the order of 20 parts per billion (ppb), and for Pd and Ge they are 0.2 and 2.0 parts per million (ppm) respectively, with a 60 μm in diameter analysis area. The accuracy of the measurements is determined by comparison with neutron activation data on monomineralic samples free of "visible" platinum group mineral inclusions. The developed quantitative microbeam technique can be used for obtaining data on the 'invisible' platinum group element - or Ga and Ge - content of sulphide and oxide minerals common in their ore deposits.

1.0 BACKGROUND

Platinum Group Elements (PGE) may be present in platinum ore deposits in two forms: as Platinum Group Minerals (PGM) and in solid solution in sulphide and oxide minerals. The importance of PGE solid solution in sulphide minerals was first discussed by Schneiderhöhn (1929)[1] in his study of Merensky Reef ores. He stated that " the fact that platinum metals occur in sulphides formed early in ores, in the state of isomorphic solid solution is of great interest and significance from a theoretical and practical point of view." Quantitative data were not presented to substantiate his thesis. However, subsequent detailed studies on all of the most important PGE deposit types - Merensky Reef, Sudbury, Norilsk, Kambalda, UG-2 and Pechenga - have shown PGM to account for only part of the assayed values.[2,3] Using the electron[4] and proton[5] microprobes pentlandite and sulpharsenides were found to carry PGE in solid solution in significant concentrations. Even with Minimum Detection Limits (MDL) of 1.2 to 3.0 ppm - for Rh and Pd - with the proton microprobe the mineralogically unaccounted fraction is significant. For example 59% of the Pd in the Sudbury ores is mineralogically unaccounted.[6]

The combination of both modes of occurrence of PGE, i.e. in solid solution and as PGM, has to be taken into account when considering the optimization of PGE recovery, or in the models for the formation of the PGE deposits.

2.0 OBJECTIVE

A microbeam technique - Secondary Ion Mass Spectrometry (SIMS) or ion probe microanalysis - with greater sensitivity than electron and proton probe microanalysis was developed for the quantification of Au and Ag in sulphide minerals.[7,8] This technique was applied successfully in more than 50 ores to obtain complete mineralogical distributions of Au or Ag, for process selection or recovery optimization.[9]

The objective of this study was to prepare mineral standards for quantitative ion probe microanalysis of Pt, Pd, Rh, Ir, Ga and Ge by ion implantation. These standards were used

to calibrate the CAMECA IMS-3f ion microprobe for the aforementioned elements in 17 mineral matrices and to establish minimum detection limits.

The concentration range that had to be addressed by SIMS was from 0.1 to 500 parts per million (ppm) by weight.

3.0 *METHODOLOGY*

Solid state standard addition, by means of ion implantation, has been praised for the production of closely matching standards necessary in quantitative ion probe microanalysis.[10]

3.1 *Ion Implantation*

A heavy ion mass accelerator (Tandetron) with a sputtering source was used to produce the implants of Pt, Pd, Rh and Ir.[11] The Ga and Ge implants were produced using the Pelletron facility (heavy ion mass separator) which has a thermal/direct current source.[8]

The acceleration voltage used was 1 MV, because of the heavy mineral matrices involved. This was done to ensure the implant is beyond the near to surface region - first few hundred Å - from where the acquired SIMS data may be anomalous.[8]

In the case of polyisotopic elements when using the internal standardization method,[12] it is preferable to implant only one isotope. This results in better accuracy, improved minimum detection limit and shorter time of analysis, by almost a factor of 2. Thus, the following isotopes were implanted ^{196}Pt, ^{110}Pd, ^{191}Ir, ^{69}Ga and ^{74}Ge. Rhodium is monoisotopic. The isotopes for implantation were selected based on their distance from the other isotopes - for better separation - in the accelerator, their abundance and potential isobaric molecular interferences. The isotopic purity of the implants was determined to be 98.5% or better by analyzing implants in silicon wafers (Appendix A7). The beam

was rastered in both directions in order to produce laterally homogeneous implants. Over-rastering by 50% on either side was used for the same purpose. The implant dose was determined from the current delivered to the specimen and the time of implantation. The specimen comprised the bottom of a deep Faraday cup. In the Pelletron facility an aperture in the front of the cup with a -300V bias prevented any electrons from escaping and thus affecting the charge measurement. The accuracy of the implant dose is determined by Rutherford Backscattering Spectrometry (RBS) of silicon wafers implanted with 2 to 5 x 10^{14} atoms/cm^{-2} of each of the six implanted elements. The RBS measurement is being carried out at the AT&T Bell Laboratories.

The area of implantation is 1.2 cm in diameter for the Ga and Ge implants and covers the entire mount in the case of the PGE implants.

3.2 Ion Probe Microanalysis

The implanted mineral standards were characterized by depth profiling using the CAMECA IMS-3f secondary ion mass spectrometer. To maximize sensitivity for Pt, Ir and Ge these elements were monitored as negative ions using a Cs^+ primary beam, while Rh, Pd and Ga were determined as positive ions with an O_2^+ primary beam.[13] The primary beam was focussed resulting in maximum ion density and the smallest spot size for a given current. The Cs^+ beam current ranged from 200 to 500 nA depending on the sputtering rate of the mineral analyzed. The O_2^+ beam current ranged from 2000 to 5000 nA. The Cs^+ primary beam was rastered over 250 μm, while rastering with the O_2^+ beam was 200 μm because of the larger spot size. Thus, flat bottomed craters were produced. The crater depth (in Å) was measured using a surface profilometer. The field and contrast apertures were set for a 60 μm analysis area and maximum transmission (F:2, C:4). Instrument settings employed and operating conditions are given in Tables 1 and 2.

Molecular interferences, are one of the three most serious obstacles in quantitative ion probe microanalysis - the other two are matrix effects and the large variations in relative ion yields from element to element.[14] Molecular interferences are molecular ions, or less

Table 1 - Instrument Settings	
Primary Beam:	Cs^+: Pt, Ir O_2^+: Rh^+, Pd^+
Primary Beam Intensity:	Cs^+: 200 - 500 nA O_2^+: 2,000 - 5,000 nA
Beam Raster:	150 - 250 µm
Contrast Aperture:	4
Field Aperture:	2
Voltage Offset:	180 - 300 V
Energy Window:	Open
Counting Time:	10 s, 0.1 s

Table 2 - Operating Conditions	
Analysis Area:	60 µm
Analysis Depth:	0.5 - 2.0 µm
Analysis Time:	4 - 8 minutes
Depth Resolution:	100 - 500 Å

common doubly charged ions, isobaric to the isotopes of interest. Molecular interferences can be heteroatomic, or made of the same atom (dimers). In this study molecular interferences were eliminated by selecting the appropriate voltage offset that nullified counts of the isobaric molecular for a given matrix and set of operating conditions. This was done by combining high mass resolution and voltage offsetting in samples known to carry the elements of interest,[15] or by voltage offsetting alone in samples "free" of the element of interest. The typical voltage offset was 200V however voltage offsets as high as 300V had to be used in few matrices with persistent molecular interferences. Naturally, voltage offsetting lowers the sensitivity of the measurement. Therefore, the minimum offset required was used for each combination of matrix/operating conditions.

During depth profiling apart from the isotopes of the element of interest, isotopes of the major elements in the minerals analyzed were also measured, to monitor stability of instrumental conditions during the analysis and to obtain count ratios. Count ratios, tend to be much more constant compared to absolute counts. Count ratios are required for the calibration curves used in external standardization.[12]

Concentration in atoms/cm^3 were calculated from the equation $C_o = F \cdot I_o / D \cdot I_i \cdot \alpha$, where C_o is the original concentration of the element, F is the implant dose in atoms/cm^2, D is the depth of the analysis required to recover all the implant in cm (1 cm = 10^8Å), I_o and I_i are the integrated counts arising from the original and implanted content of the element of interest. For polyisotopic elements I_o and I_i refer to different isotopes therefore require conversion to the same isotope. This is done by using the natural abundance of the isotopes and the correction for isotopic instrumental enhancement of the lighter isotope. Finally, α is the isotopic abundance of the isotope used in the analysis. The concentrations can readily be converted from at/cm^3 to ppm (wt) by using the density of the mineral, the atomic weight of the isotope measured and the Avogadro number.

4.0 RESULTS

The list of minerals implanted with each of the following elements Pt, Pd, Rh, Ir, Ga and Ge is given in Table 3. Each implanted mineral was depth profiled two times. In cases where the concentration profiles were not closely comparable more profiles were acquired. After calculating the implant concentration at various depths, the concentrations were plotted against the corresponding isotopic count ratios and calibration curves were drawn. The calibration curves are mineral - and element - specific. The curves were grouped based on the common major element isotope used in the count ratio (Appendices A1 - A6).

The sensitivity, expressed as the number of counts acquired in 10s - the counting time per measurement cycle - per ppm (wt%) ranges from 0.3 (Pd in chromite) to 400 (Rh in pyrrhotite. Of the elements examined in this study, SIMS is most sensitive for detecting Pt, Rh, Ir and Ga and less sensitive for Pd and Ge. The elemental sensitivity varied with mineral matrix, grain size, sample charging and operating conditions. The MDL's were measured under optimal operating conditions (no charging, mineral grains larger than 100 μm in diameter) using a 50 μm raster. It represents 3σ of the background counts in mineral samples that are not likely to have the element measured. The MDL's are given in Table 4. The precision of the determinations expresses the degree of scatter - at a 95% significance level - of the points used to draw a particular calibration curve (Appendices A1 - A6). The scatter is mostly affected by the depth measurement of the crater produced and to a lesser extent by sample charging. The accuracy of the technique is measured by comparison of data from neutron activation and ion probe on selected mineral grains which are monomineralic - less than 5% other phases - are free of PGM and have detectable by the ion probe concentrations of the element of interest.

TABLE 3 - ION IMPLANTED MINERALS

	IMPLANTED ISOTOPE					
	^{196}Pt	$^{105,106}Pd$	^{103}Rh	^{191}Ir	^{69}Ga	^{74}Ge
Pyrite					+	+
Pyrrhotite	+	+	+	+		
Troilite	+		+	+		
Pentlandite	+	+	+	+		
Chalcopyrite	+	+	+	+	+	+
Millerite	+	+	+	+		
Nickeline	+	+	+	+		
Maucherite	+		+	+		
Heazelwoodite	+					
Gersdorffite	+		+			
Covellite	+	+	+	+	+	+
Chalcocite	+	+	+	+	+	+
Bornite	+	+	+	+	+	+
Enargite					+	+
Sphalerite					+	
Magnetite	+	+	+	+	+	+
Chromite	+	+	+	+		

TABLE 4 - MINIMUM DETECTION LIMITS (3σ)

	ppb				ppm	
	Pt	Rh	Ir	Ga	Pd	Ge
Pyrite	-	-	-	40	-	2.5
Pyrrhotite	25	7	12	-	0.1	-
Pentlandite	17	15	22	-	0.2	-
Chalcopyrite	14	15	8	50	0.1	2.2
Chalcocite	80	15	70	17	0.1	1.7
Sphalerite	-	-	-	800	-	-
Magnetite	20	20	6	170	0.4	1.5
Chromite	40	500	10	-	8.0	-
Nickeline	7	15	7	-	0.3	-

5.0 REFERENCES

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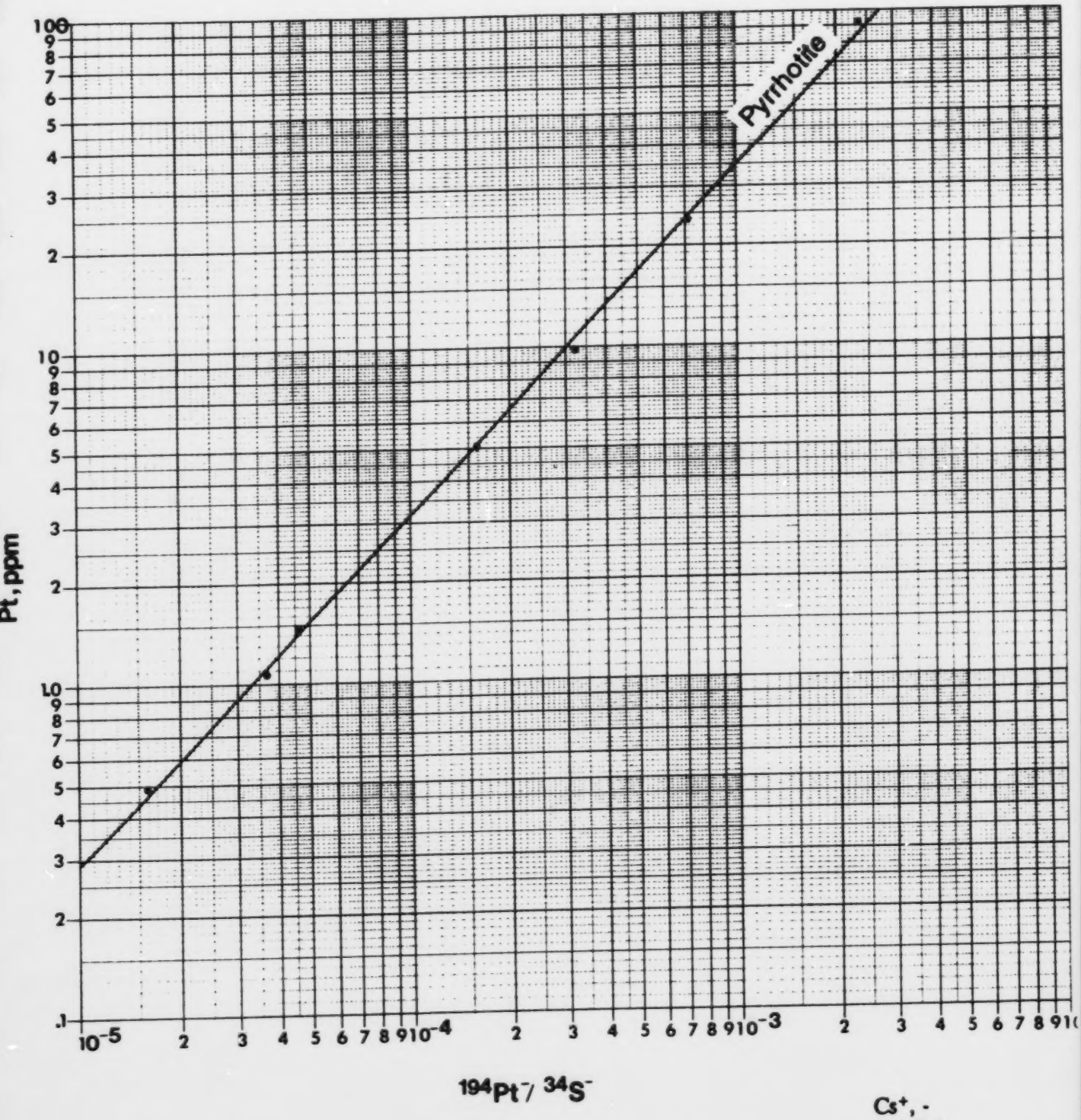
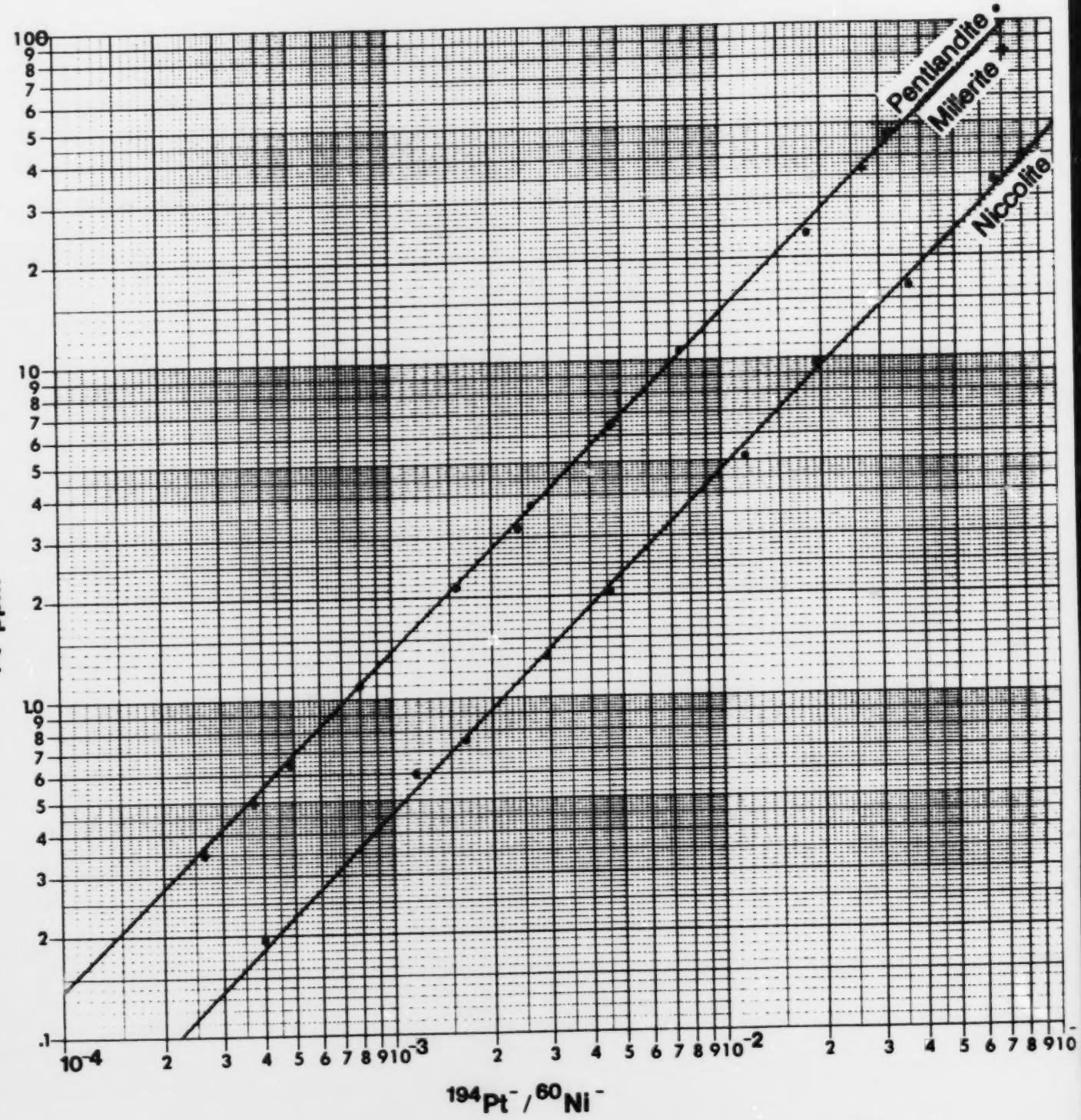
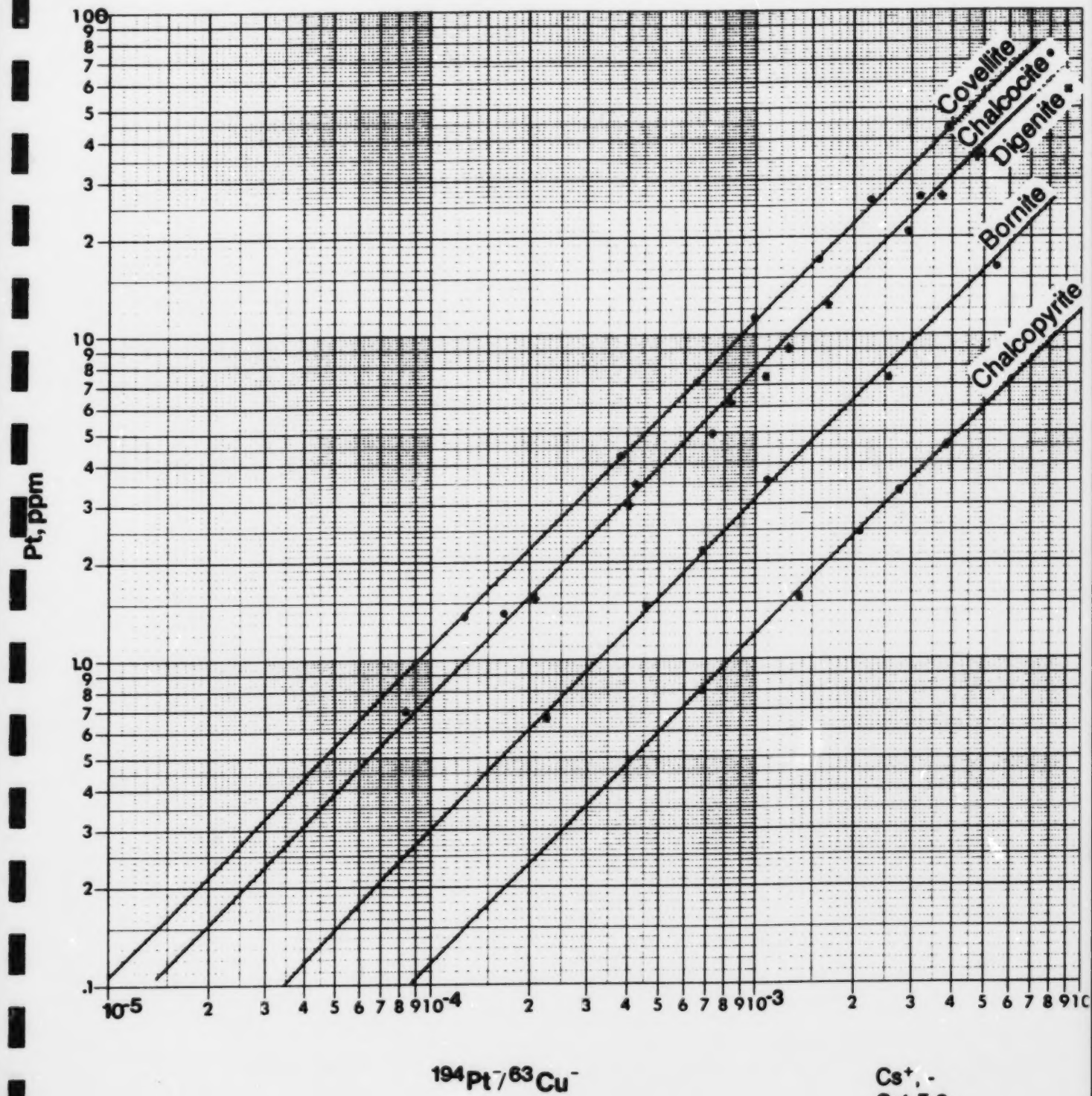
APPENDIX A1

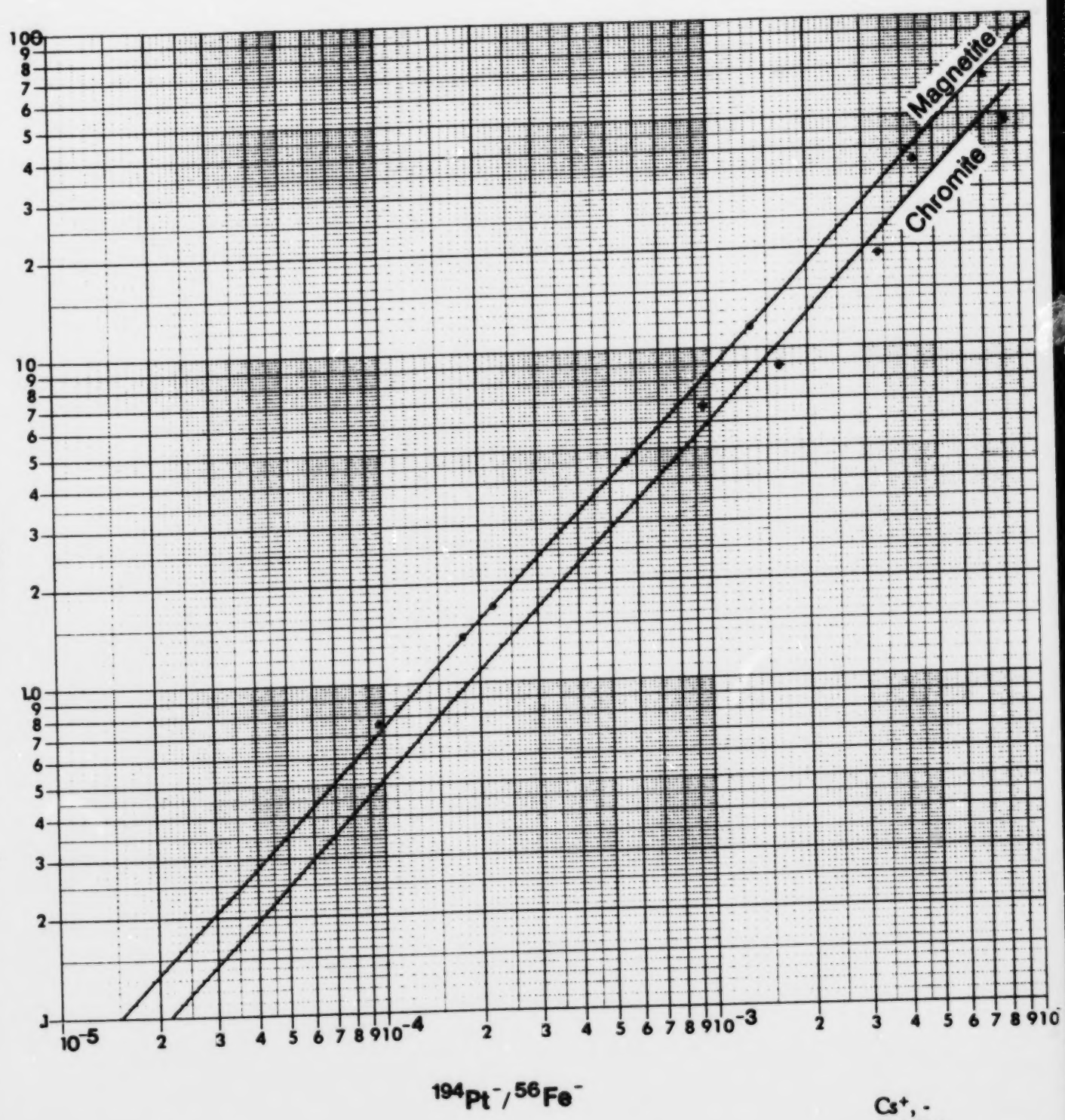
CALIBRATION CURVES FOR THE QUANTIFICATION OF PLATINUM
IN SULPHIDE, ARSENIDE AND OXIDE MINERALS BY ION PROBE MICROANALYSIS



Cs^+, -
C:4 F:2
200V, open
250 µm, 500 nA

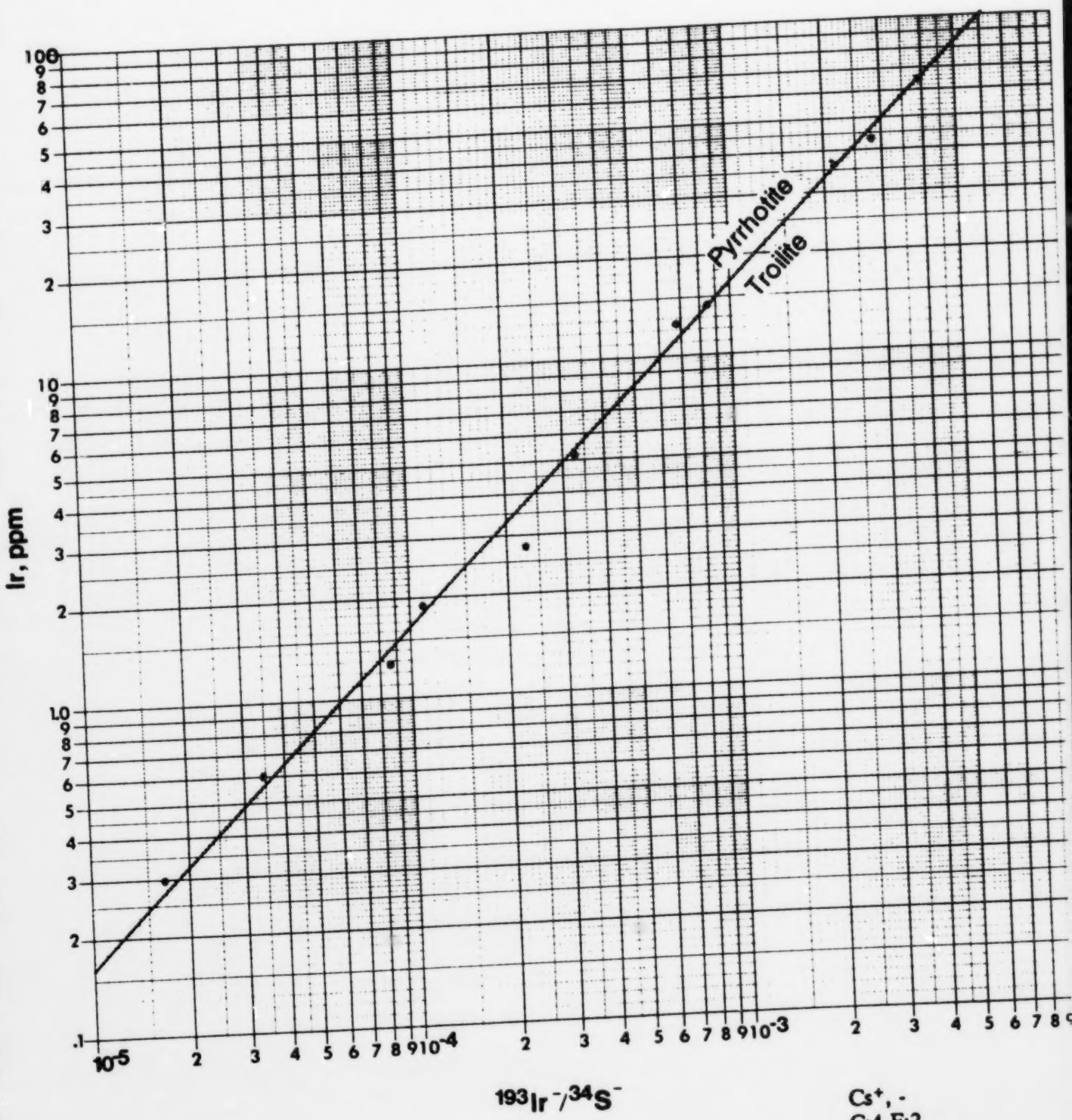

Pentlandite
Millerite
Niccolite
Pt ppm
100
10
1.0
.1
$^{194}Pt^- / {}^{60}Ni^-$
10^{-4}
10^{-3}
10^{-2}
Cs^+, -
C:4 F:2
200V, open
250 µm, 500 nA

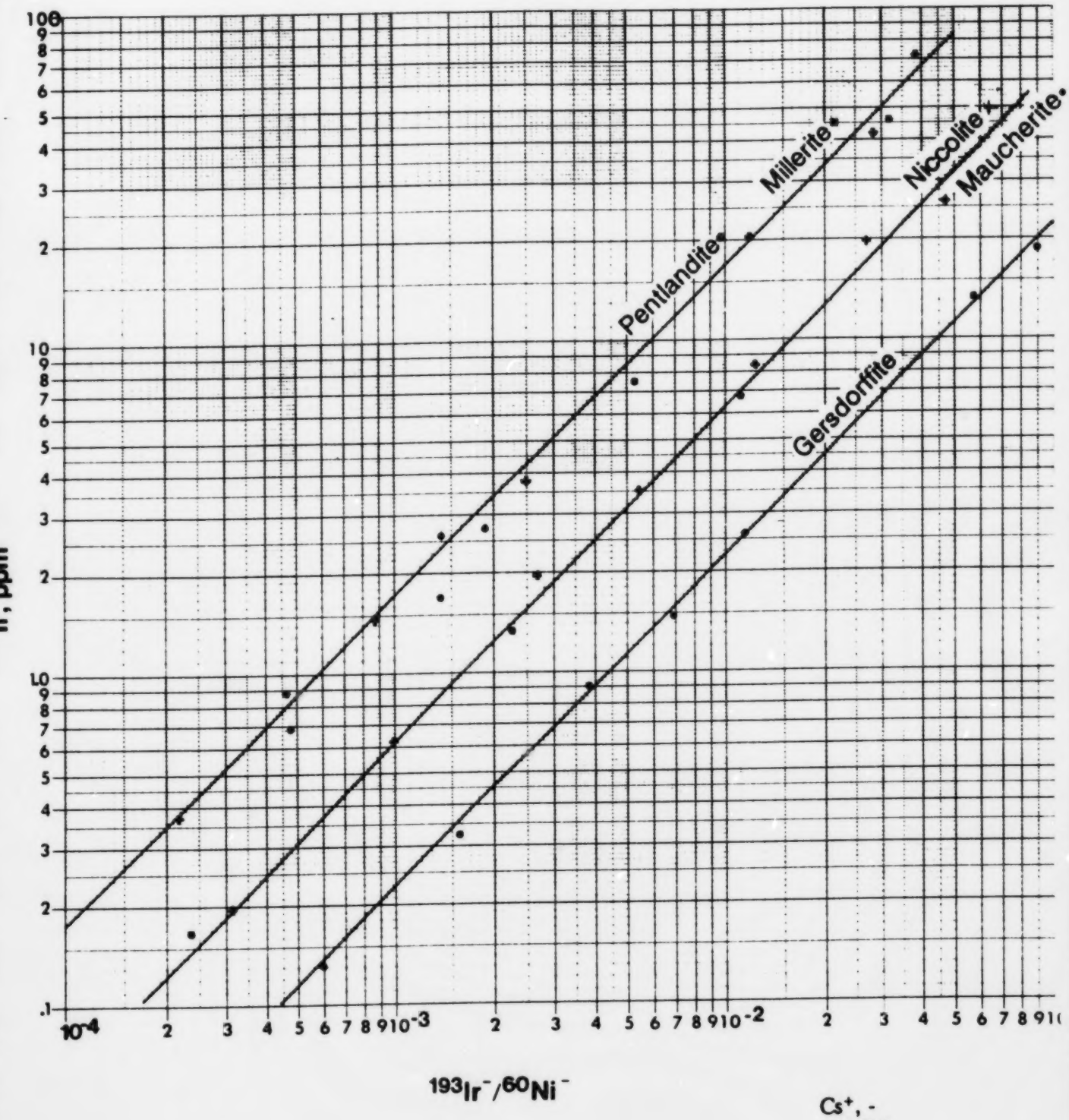

Covellite
Chalcocite
Digenite
Bornite
Chalcopyrite
Pt, ppm
$^{194}Pt^{-}/^{63}Cu^{-}$
Cs^{+}, -
C:4 F:2
200V, open
500 nA


Magnetite
Chromite
Pt, ppm
$^{194}Pt^-/^{56}Fe^-$
Cs^+, -
C:4 F:2
200V, open
250 µm, 500 nA

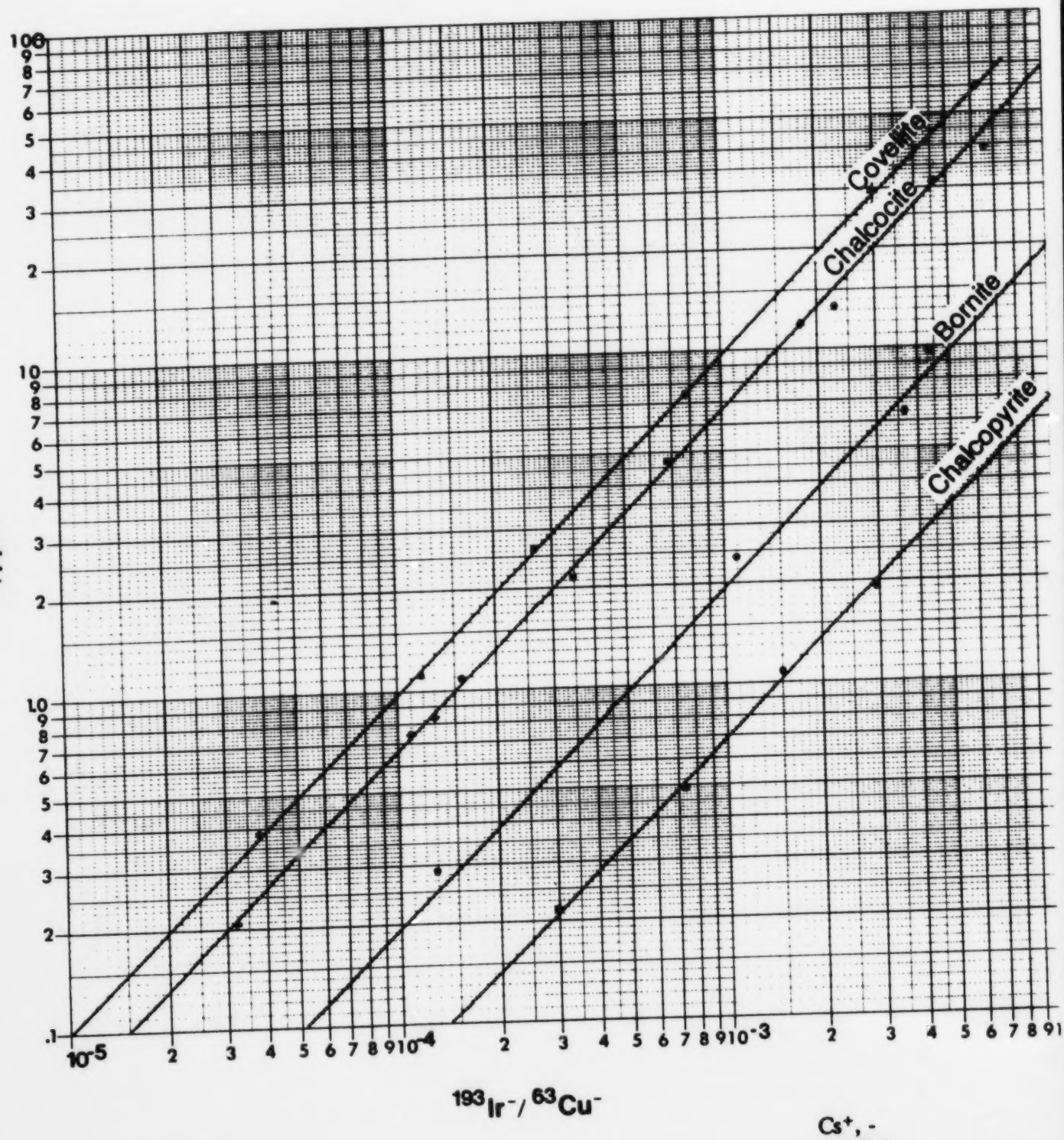
APPENDIX A2

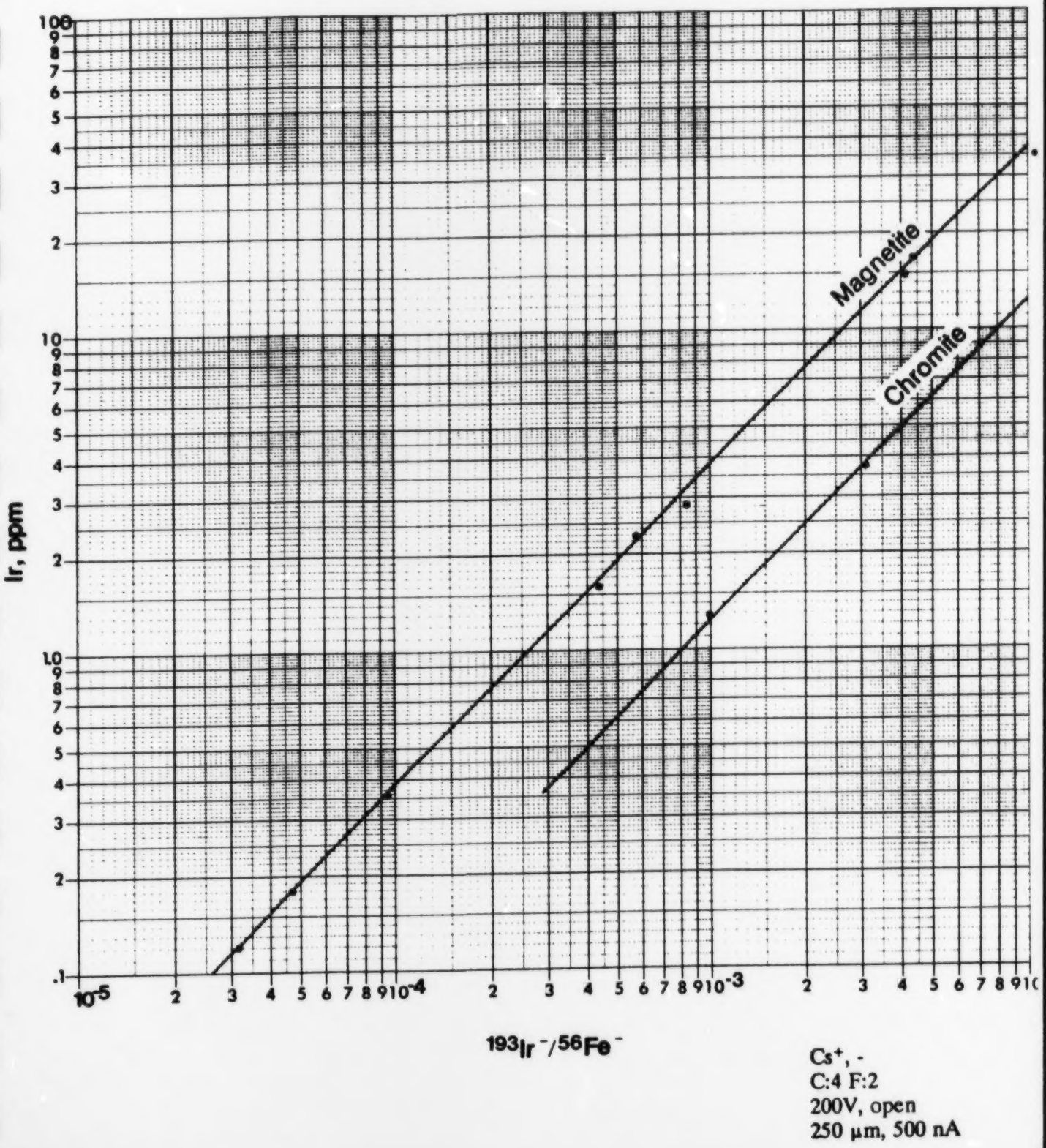
CALIBRATION CURVES FOR THE QUANTIFICATION OF IRIDIUM IN SULPHIDE, ARSENIDE AND OXIDE MINERALS BY ION PROBE MICROANALYSIS


Ir, ppm
100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
.1
10-5
2
3
4
5
6
7
8
9
10-4
2
3
4
5
6
7
8
9
10-3
2
3
4
5
6
7
8
9
Pyrrhotite
Troilite
193Ir-/34S-
Cs+, -
C:4 F:2
200V, open
250 µm, 500 nA



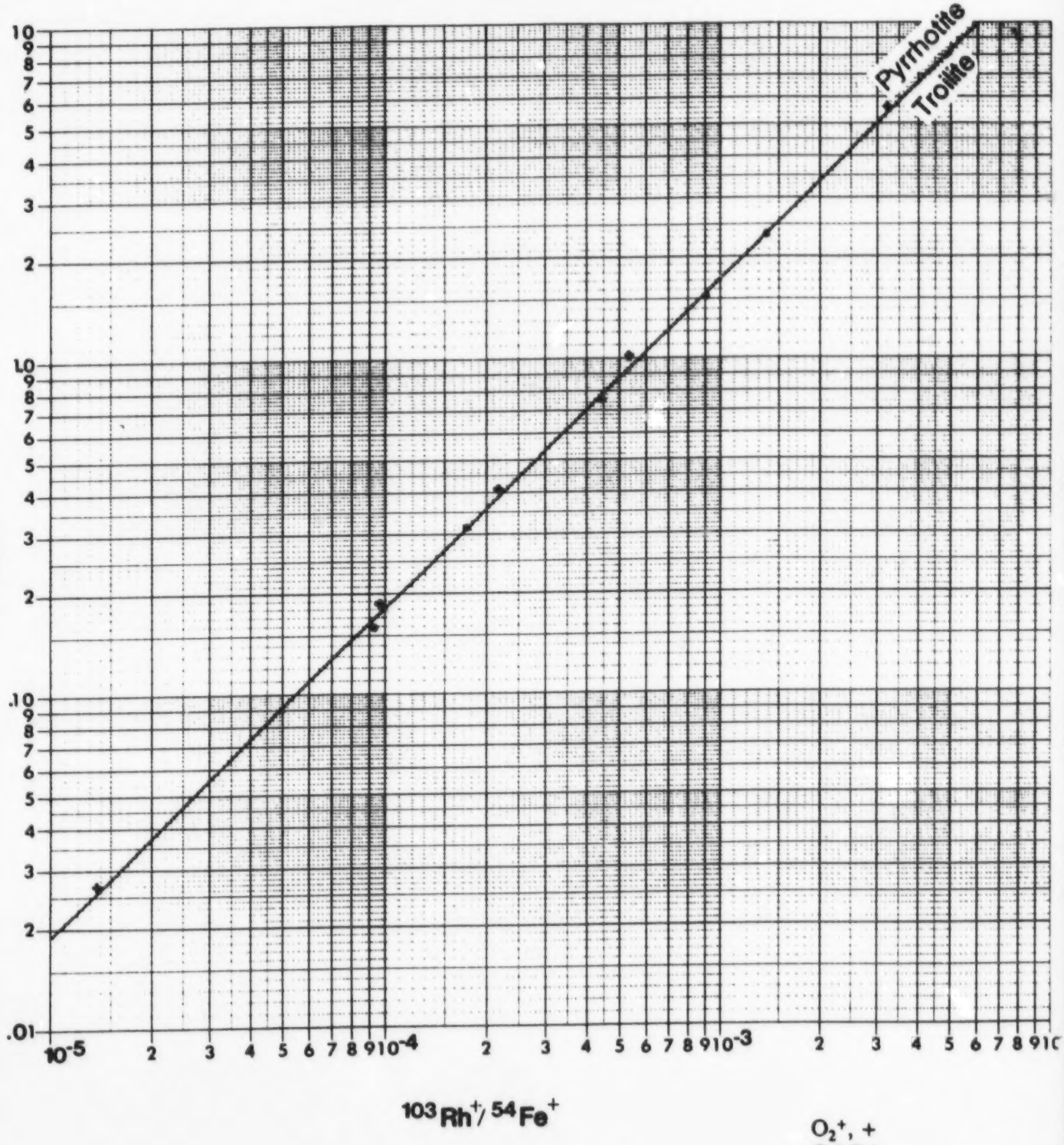
Cs^+, -
C:4 F:2
200V, open
250 μm, 500 nA


Ir, ppm
Covellite
Chalcocite
Bornite
Chalcopyrite
$^{193}Ir^-/^{63}Cu^-$
Cs^+, -
C:2 F:2
200V, open
250 µm, 500 nA

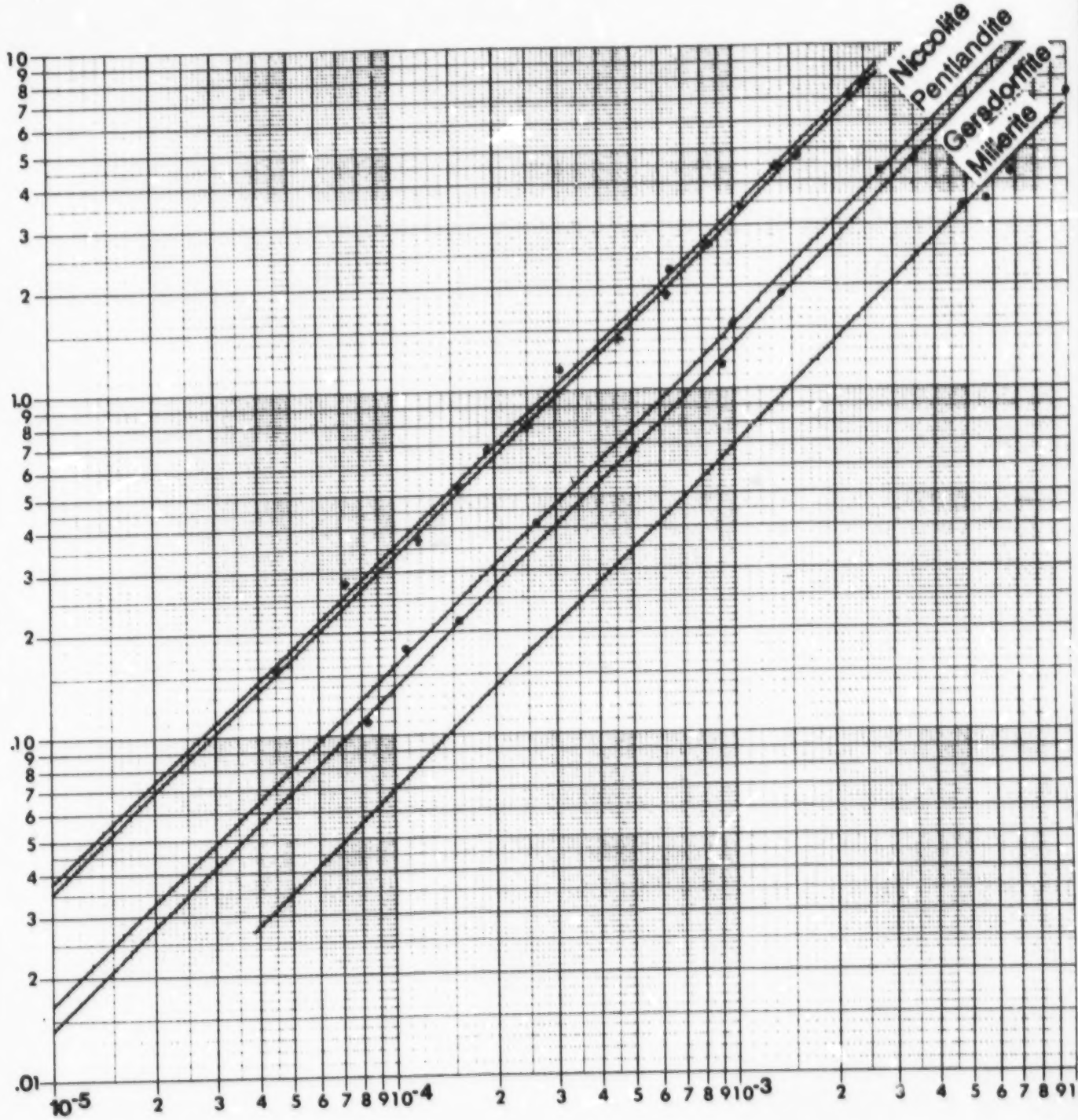

Ir, ppm
100
10
1.0
.1
10-5
10-4
10-3
Magnetite
Chromite
193Ir-/56Fe-
Cs+, -
C:4 F:2
200V, open
250 µm, 500 nA

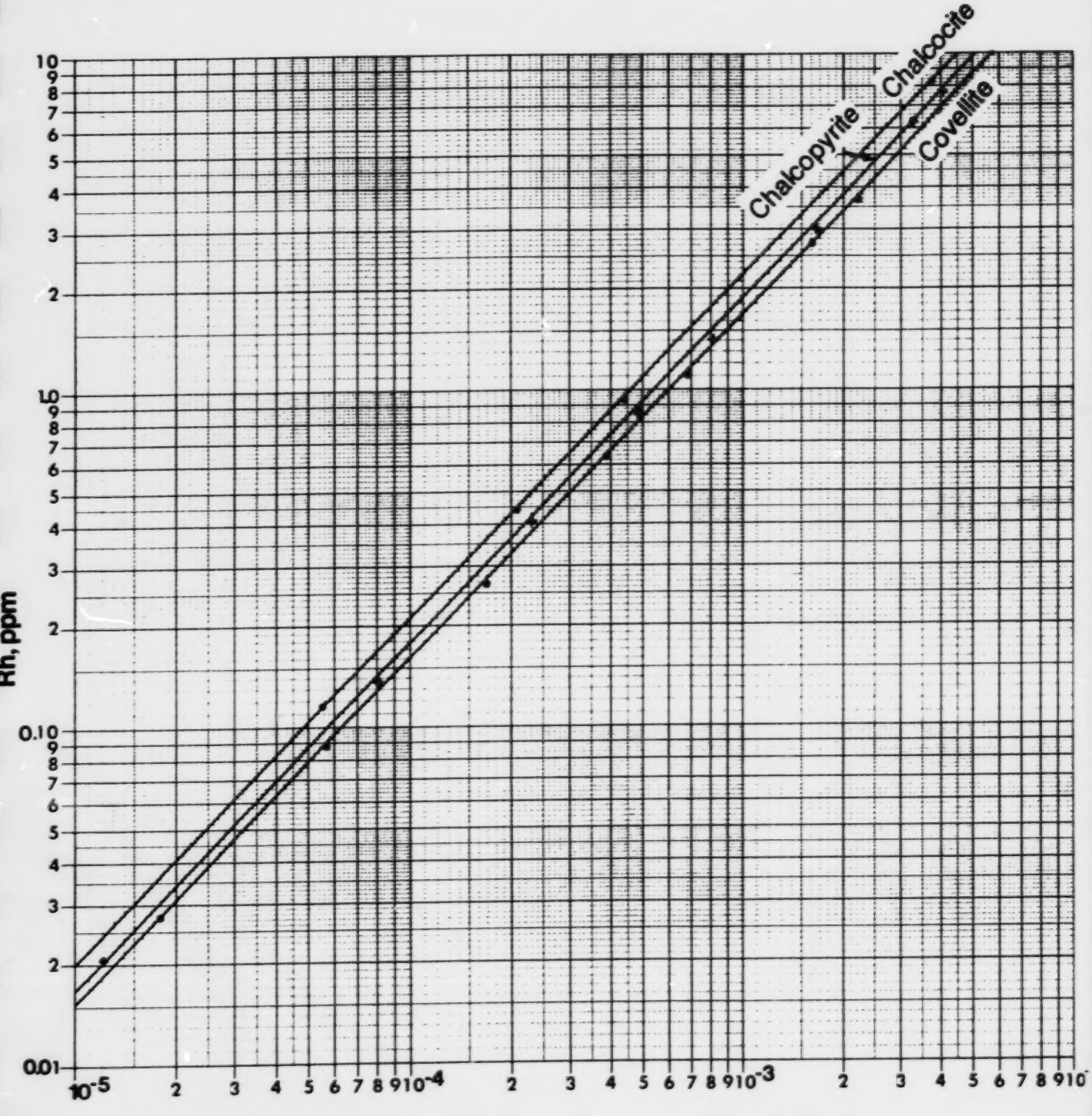
APPENDIX A3

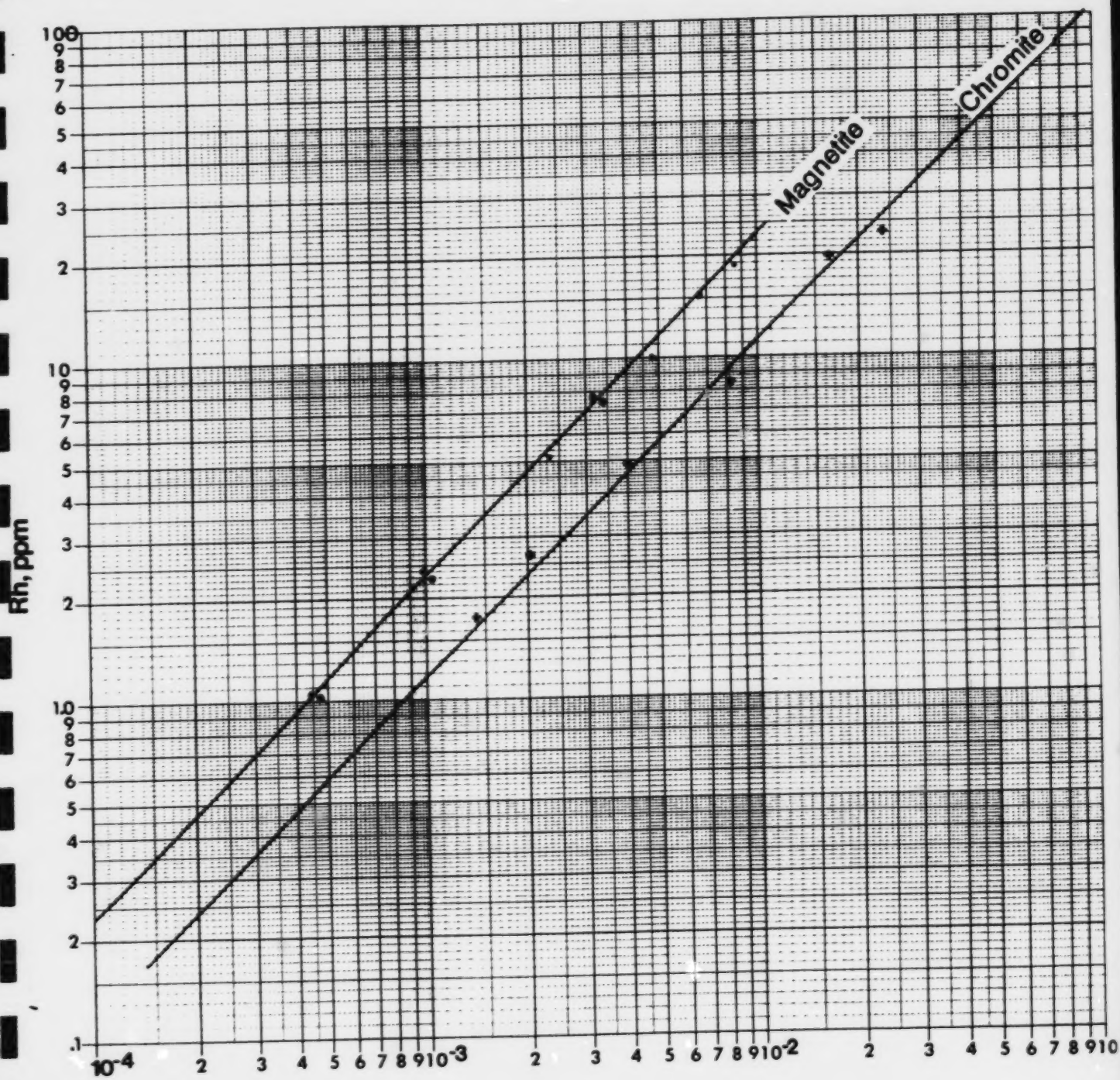
CALIBRATION CURVES FOR THE QUANTIFICATION OF RHODIUM IN SULPHIDE, ARSENIDE AND OXIDE MINERALS BY ION PROBE MICROANALYSIS



O_2^+, +
C:4 F:2
200V, open
200 μm, 4000 nA


Niccolite
Pentlandite
Gersdorffite
Millerite
Rh ppm
10
9
8
7
6
5
4
3
2
1.0
.10
.01
10^{-5}
10^{-4}
10^{-3}
$^{103}Rh^{+}/^{60}Ni^{+}$
O_2^+, +
C:4 F:2
200V, open
200 µm, 4000 nA

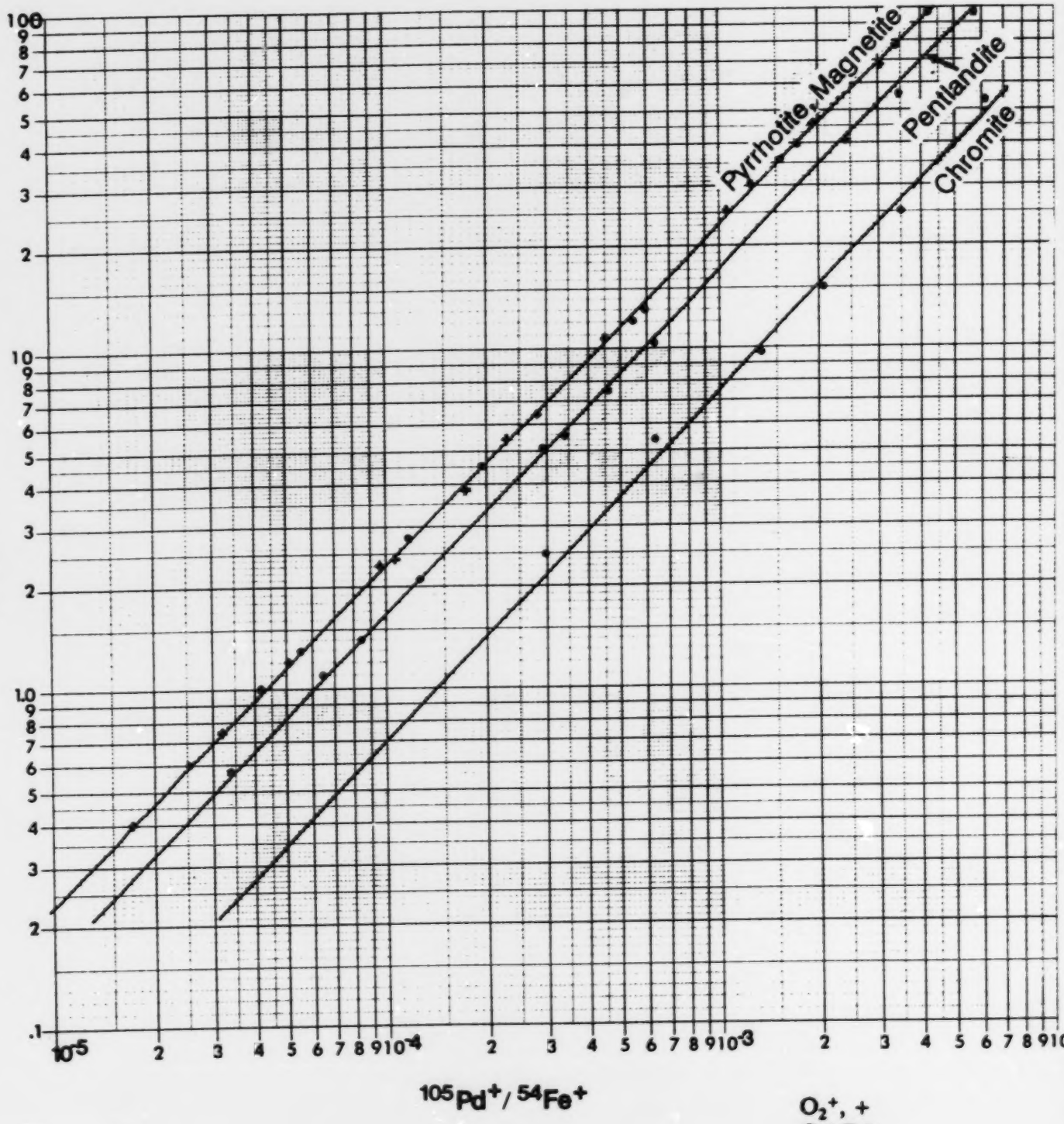

Chalcopyrite
Chalcocite
Covellite
Rh, ppm
10
9
8
7
6
5
4
3
2
1.0
0.10
0.01
10-5
10-4
10-3
103Rh+/63Cu+
O2+, +
C:4 F:2
200V, open
200 µm, 4000 nA

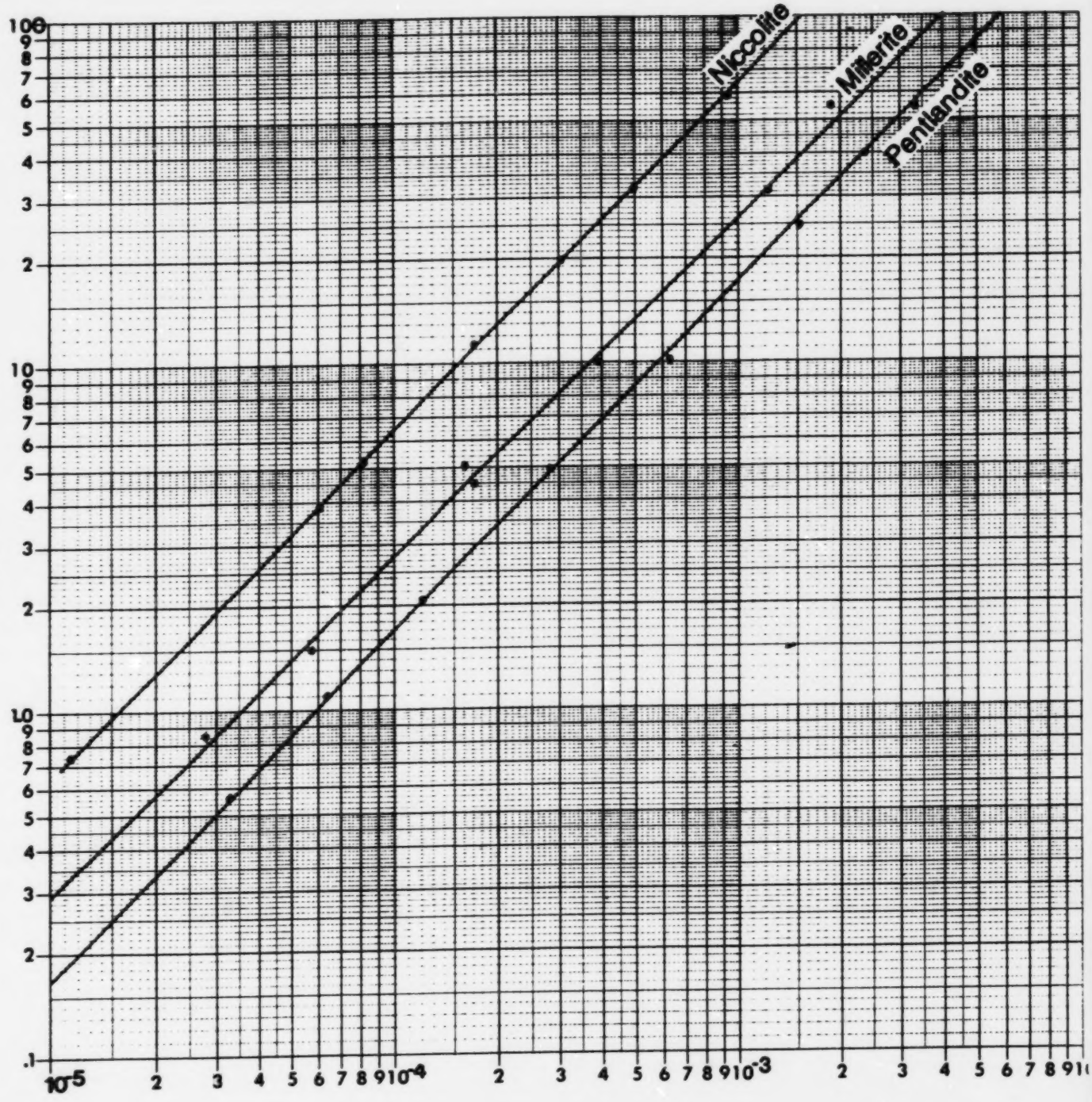


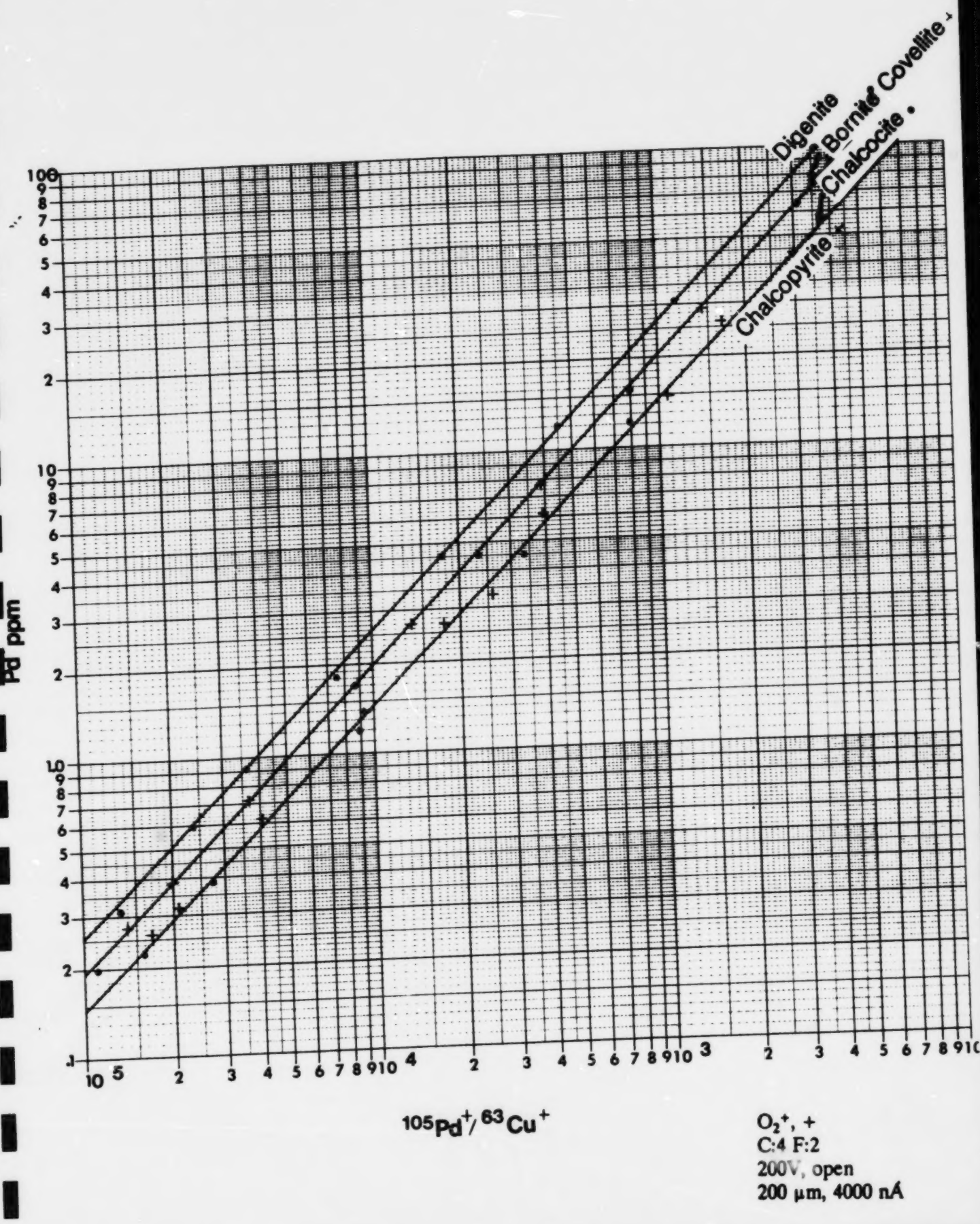
O_2^+, +
C:4 F:2
200V, open
200 µm, 4000 nA

APPENDIX A4

CALIBRATION CURVES FOR THE QUANTIFICATION OF PALLADIUM IN SULPHIDE, ARSENIDE AND OXIDE MINERALS BY ION PROBE MICROANALYSIS

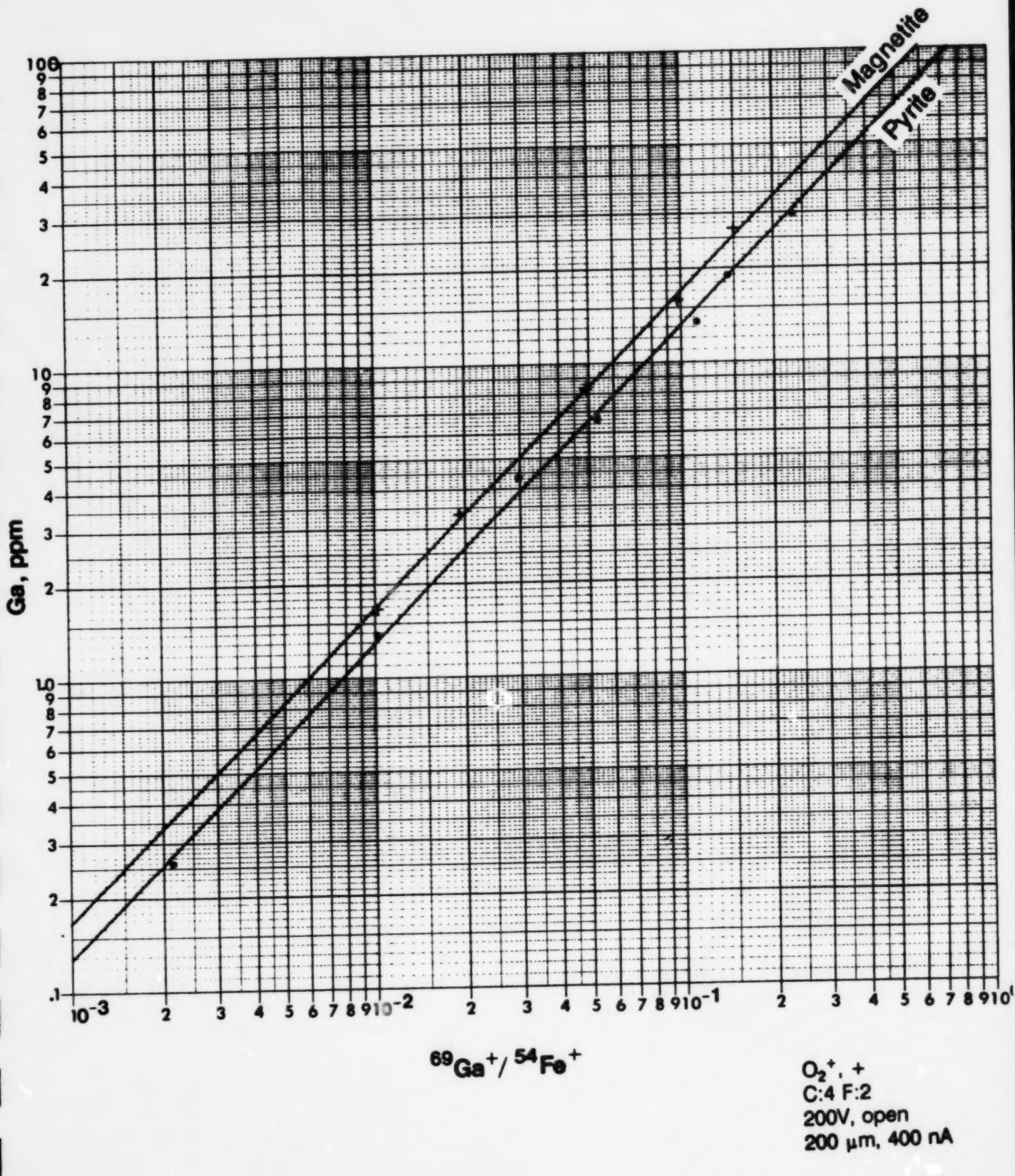

Pyrrhotite, Magnetite
Pentlandite
Chromite
Pd, ppm
$^{105}Pd^{+}/^{54}Fe^{+}$
O_2^+, +
C:4 F:2
200V, open
200 µm, 4000 nA

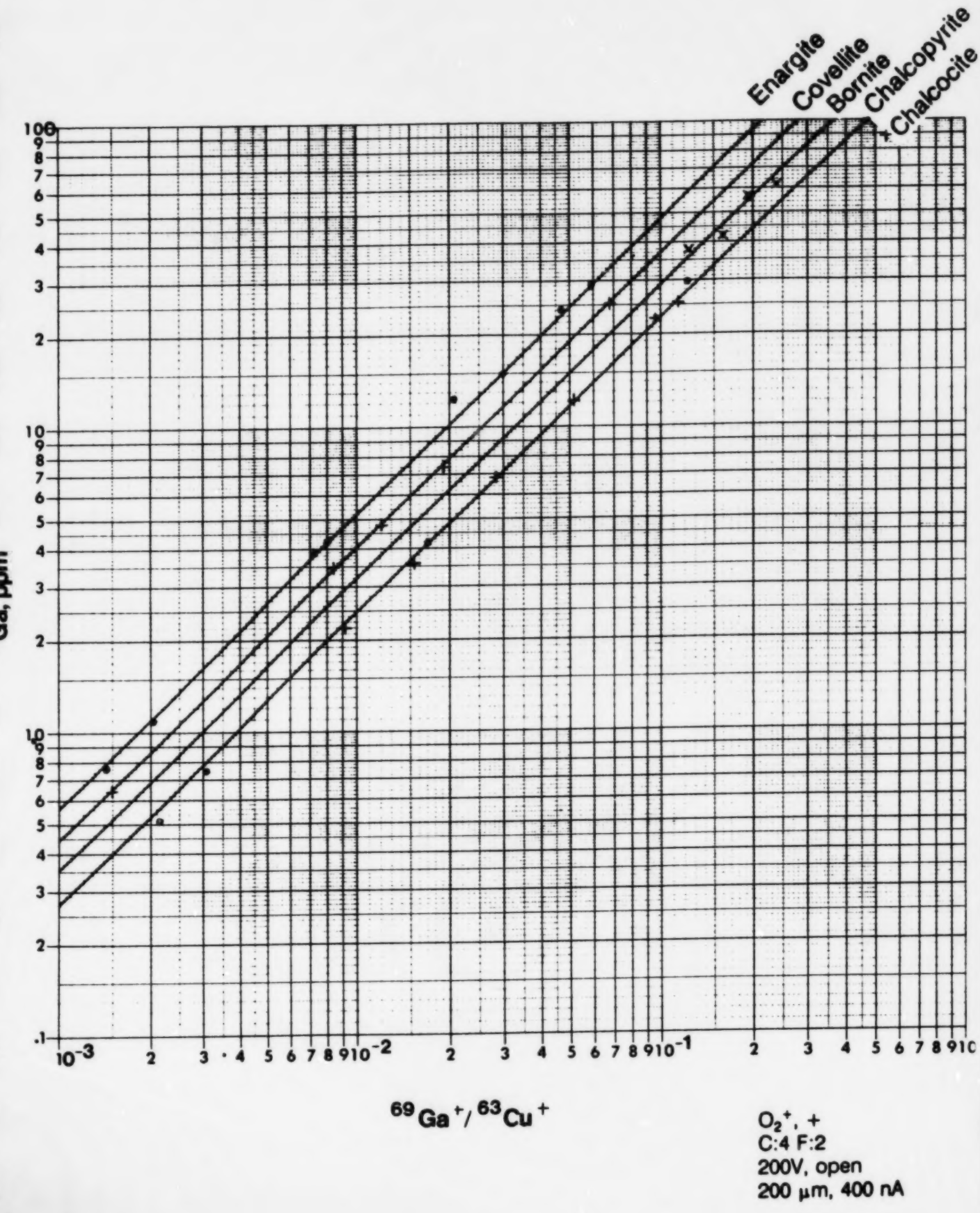

Niccolite
Millerite
Pentlandite
Pd, ppm
100
10
1.0
.1
10-5
10-4
10-3
105Pd+/60Ni+
O2+, +
C:4 F:2
200V, open
200 µm, 4000 nA

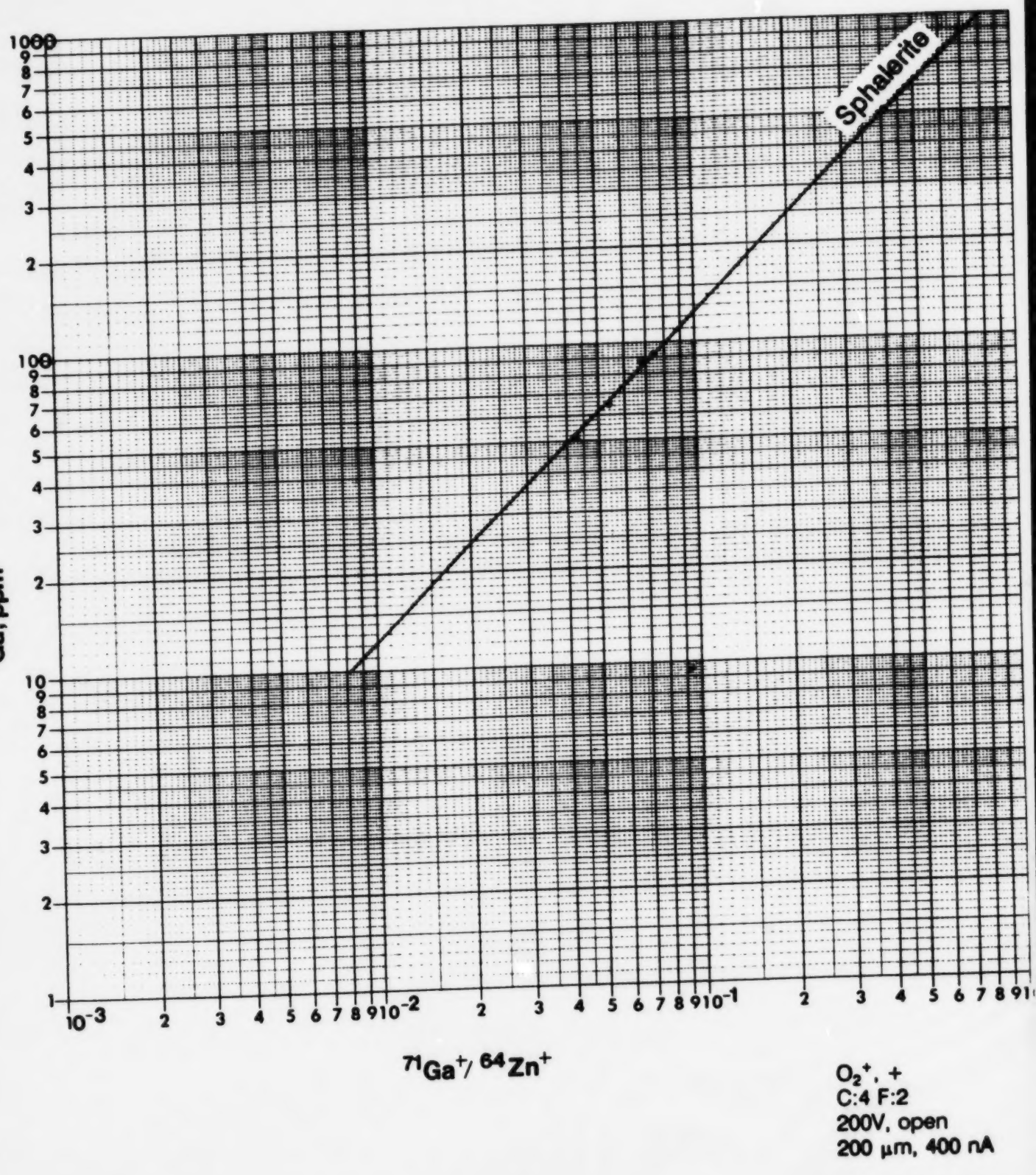

Digenite
Bornite
Covellite
Chalcocite
Chalcopyrite
Pd ppm
$^{105}Pd^{+}/^{63}Cu^{+}$
O_2^{+}, +
C:4 F:2
200V, open
200 µm, 4000 nA

APPENDIX A5

CALIBRATION CURVES FOR THE QUANTIFICATION OF GALLIUM IN SULPHIDE MINERALS BY ION PROBE MICROANALYSIS

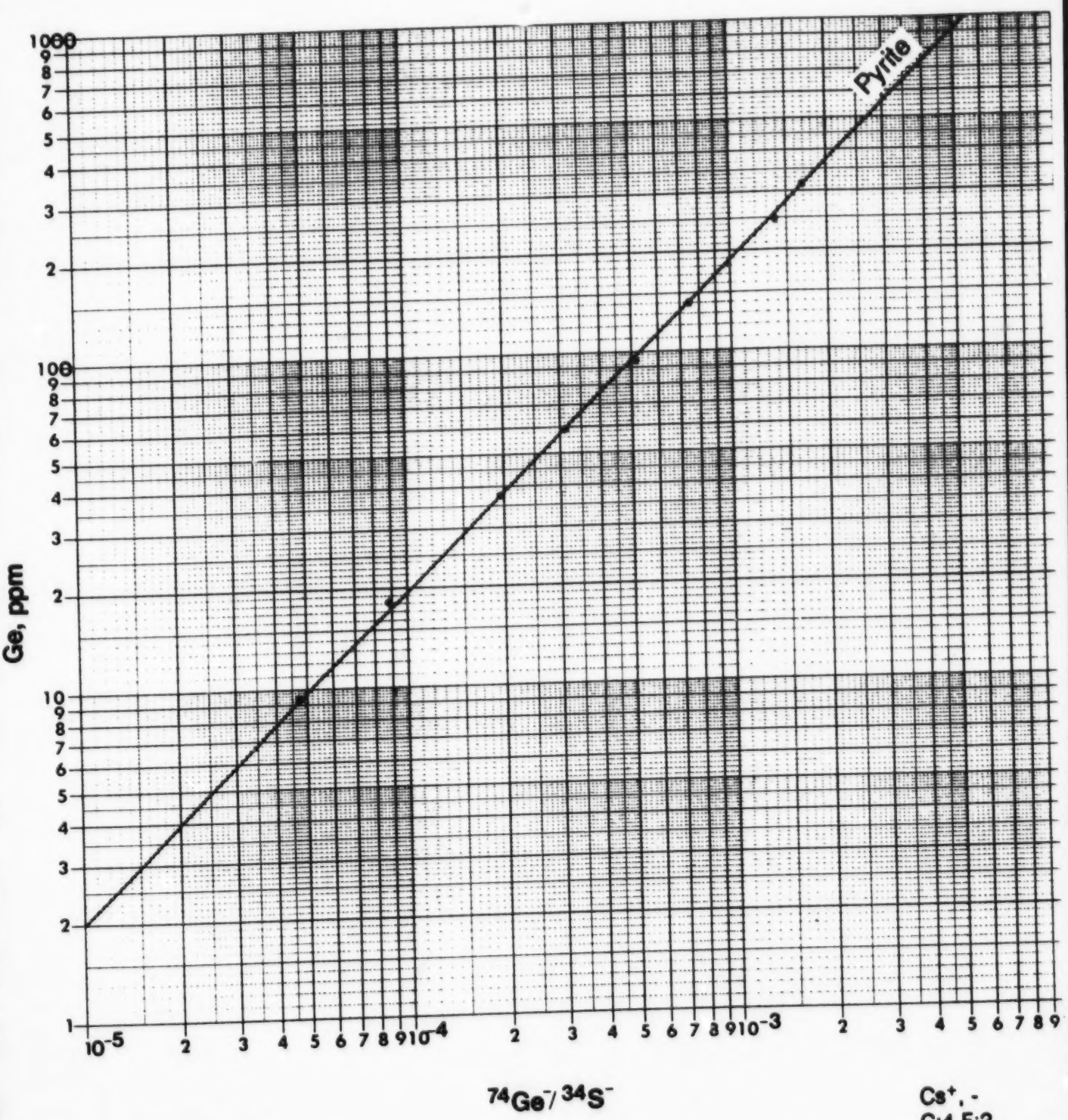

Magnetite
Pyrite
Ga, ppm
100
10
1.0
.1
10^{-3}
10^{-2}
10^{-1}
$^{69}Ga^+ / ^{54}Fe^+$
O_2^+, +
C:4 F:2
200V, open
200 µm, 400 nA

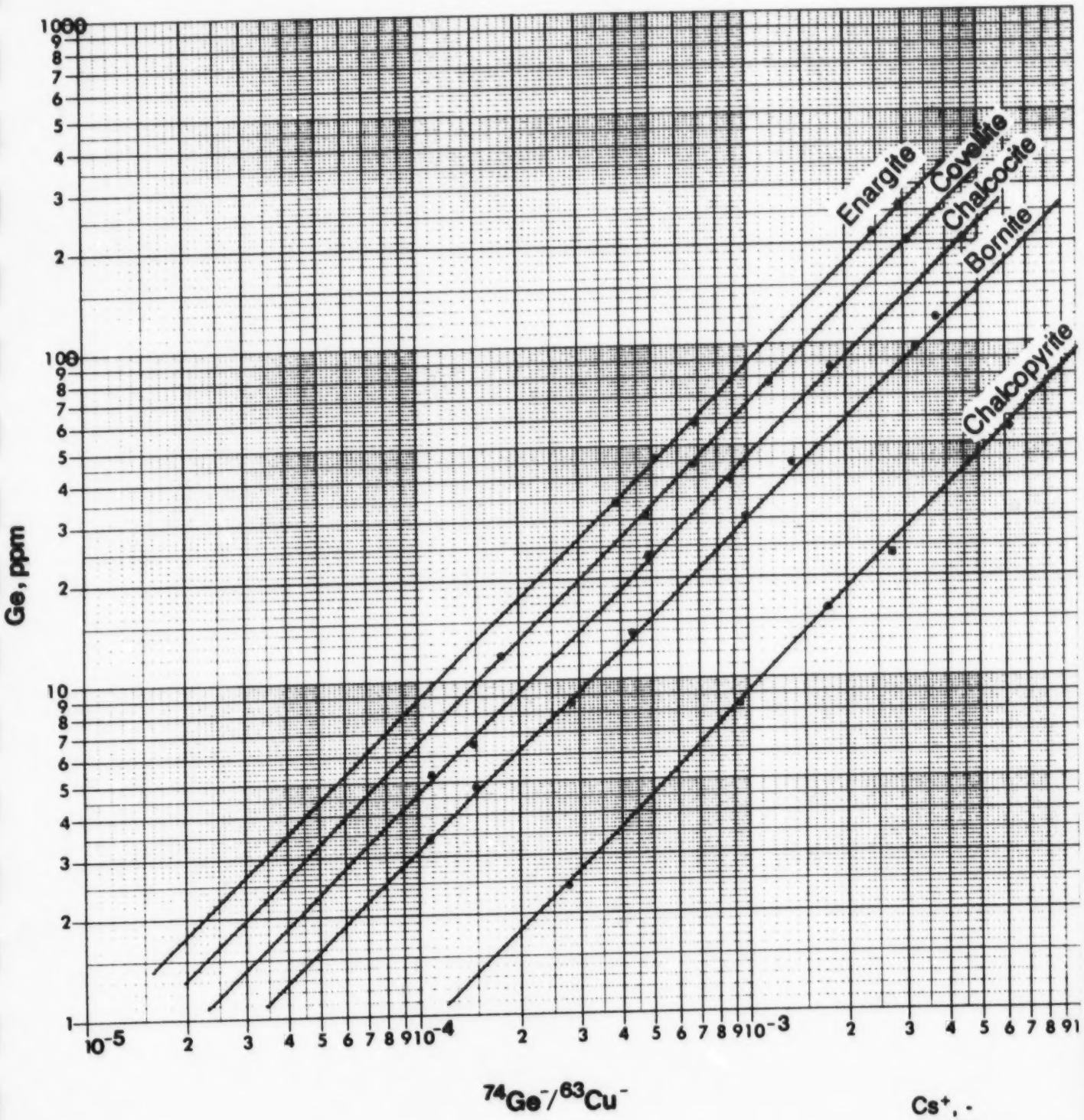

Enargite
Covellite
Bornite
Chalcopyrite
Chalcocite
Ga, ppm
$^{69}Ga^{+}/^{63}Cu^{+}$
O_2^+, +
C:4 F:2
200V, open
200 μm, 400 nA

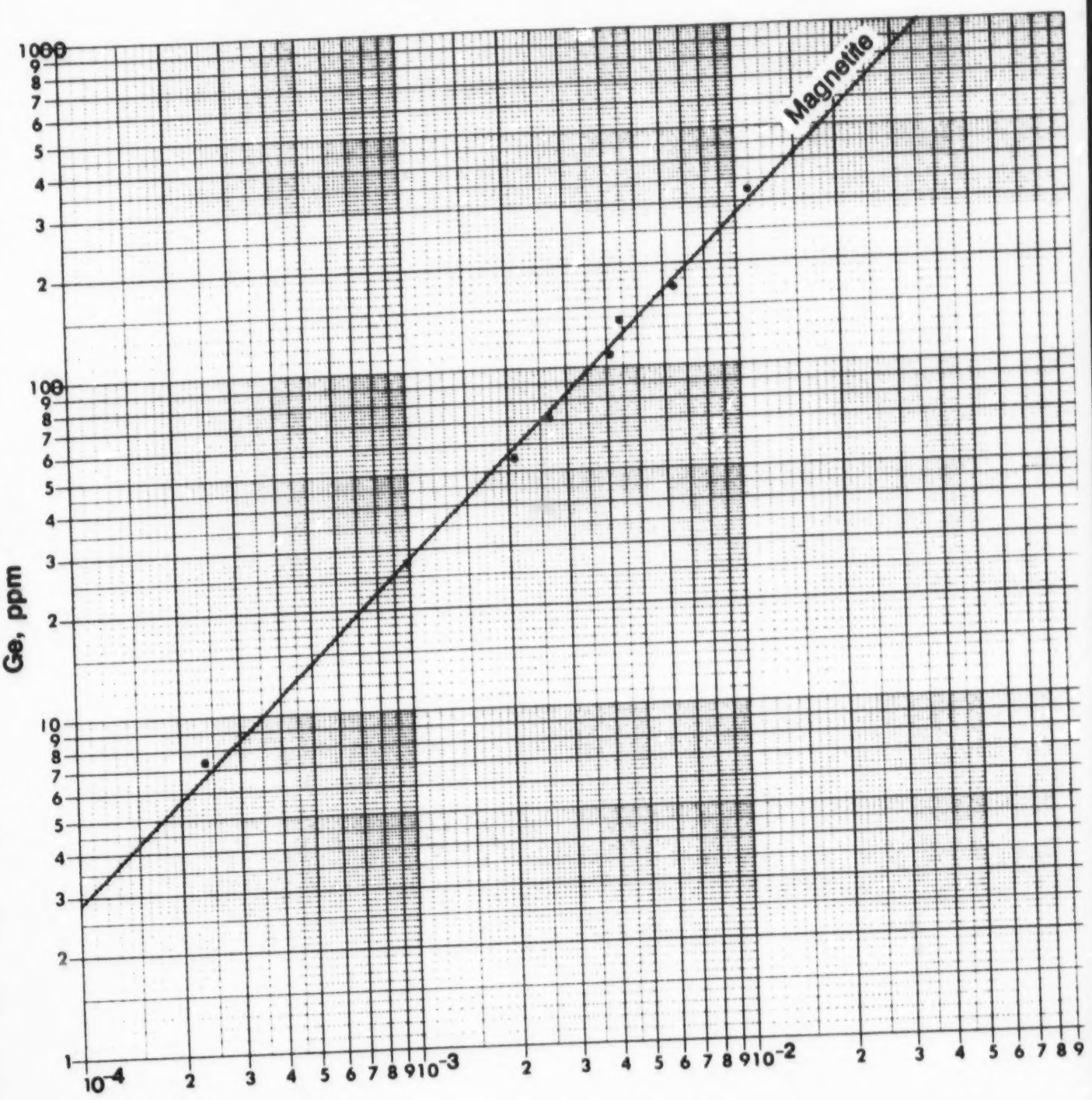

Sphalerite
Ga, ppm
1000
100
10
1
10^{-3}
10^{-2}
10^{-1}
$^{71}Ga^{+}/\,^{64}Zn^{+}$
O_2^{+}, +
C:4 F:2
200V, open
200 µm, 400 nA

APPENDIX A6

CALIBRATION CURVES FOR THE QUANTIFICATION OF GERMANIUM IN SULPHIDE MINERALS BY ION PROBE MICROANALYSIS


Pyrite
Ge, ppm
1000
100
10
1
10^{-5}
10^{-4}
10^{-3}
$^{74}Ge^-/^{34}S^-$
Cs^+, -
C:4 F:2
200V, open
500 nA

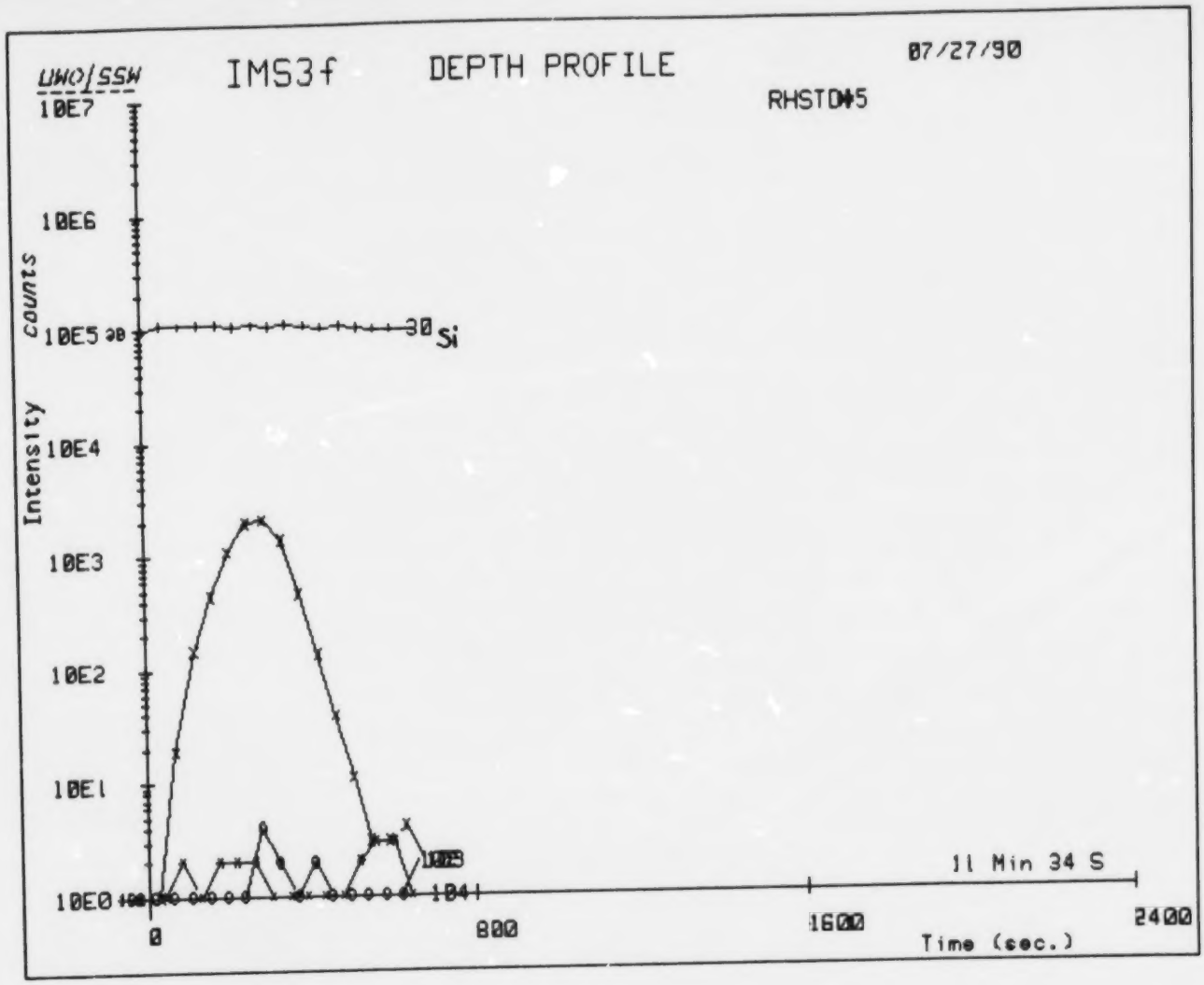

Enargite
Covellite
Chalcocite
Bornite
Chalcopyrite
Ge, ppm
$^{74}Ge^-/^{63}Cu^-$
Cs^+, -
C:4 F:2
200V, open
500 nA



Cs^{+}, -
C:4 F:2
200V, open
250 µm, 500 nA

APPENDIX A7

IN-DEPTH CONCENTRATION PROFILES OF Pt, Ir, Rh, Ga AND Pd IN SILICON USED FOR ESTIMATION OF IMPLANT PURITY



SAMPLE:RHSTD#5
DATE:07/27/90
PRIMARY IONS : CS +
SECONDARY IONS : -
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 673 NANO AMP
HIGH VOLTAGE : 9.8 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

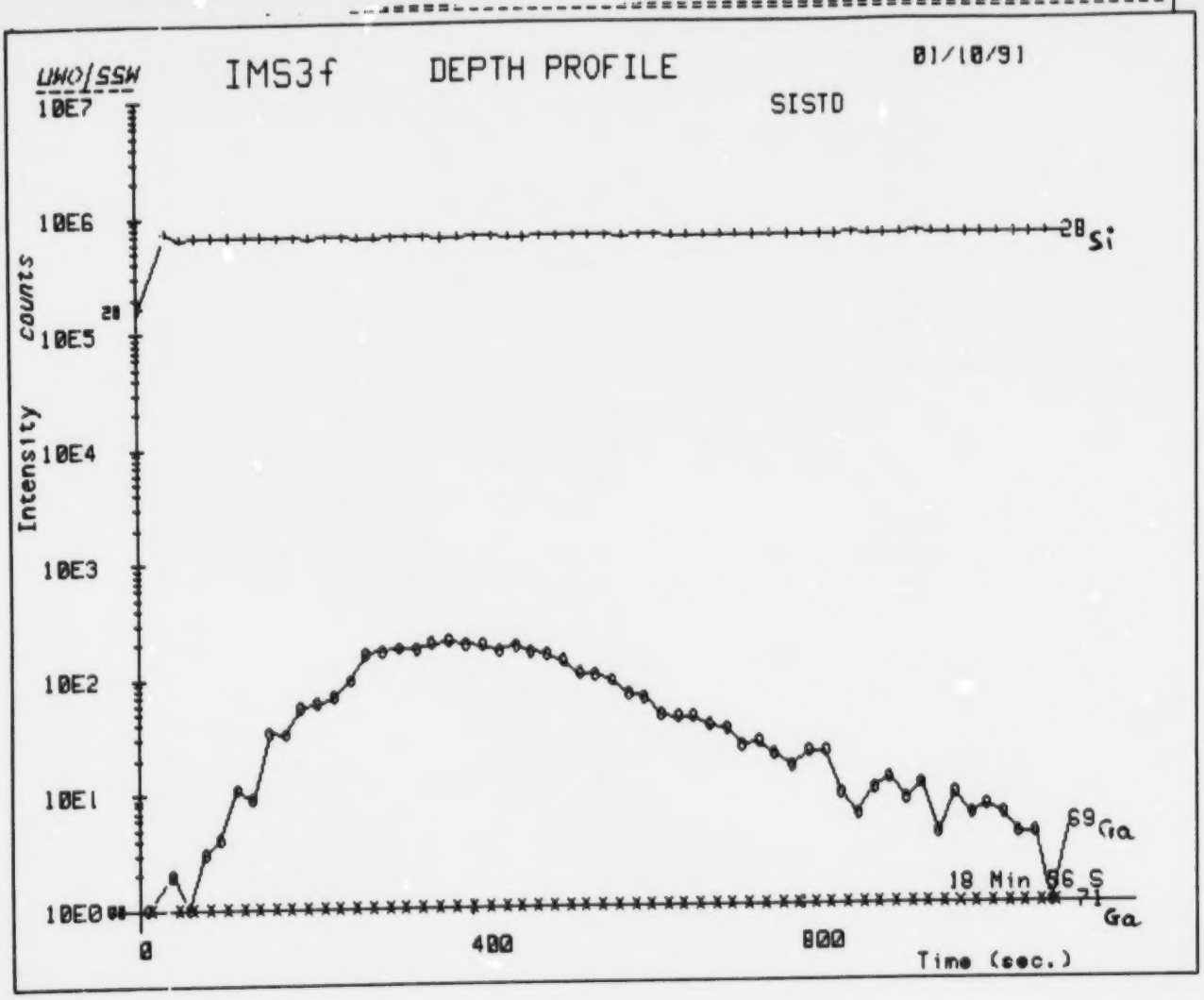
.....TOTAL COUNTS IN PROFILE.....

30	Si	1675974
102	Ru	12
103	Rh	7787
104	Pd	19

PROFILE TIME 694.000 SEC.
NUMBER CYCLES 16.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
30	665380742
102	48



SAMPLE:SISTD
DATE:01/10/91
PRIMARY IONS : OX +
SECONDARY IONS : +
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 3749 NANO AMP
HIGH VOLTAGE : 12.4 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

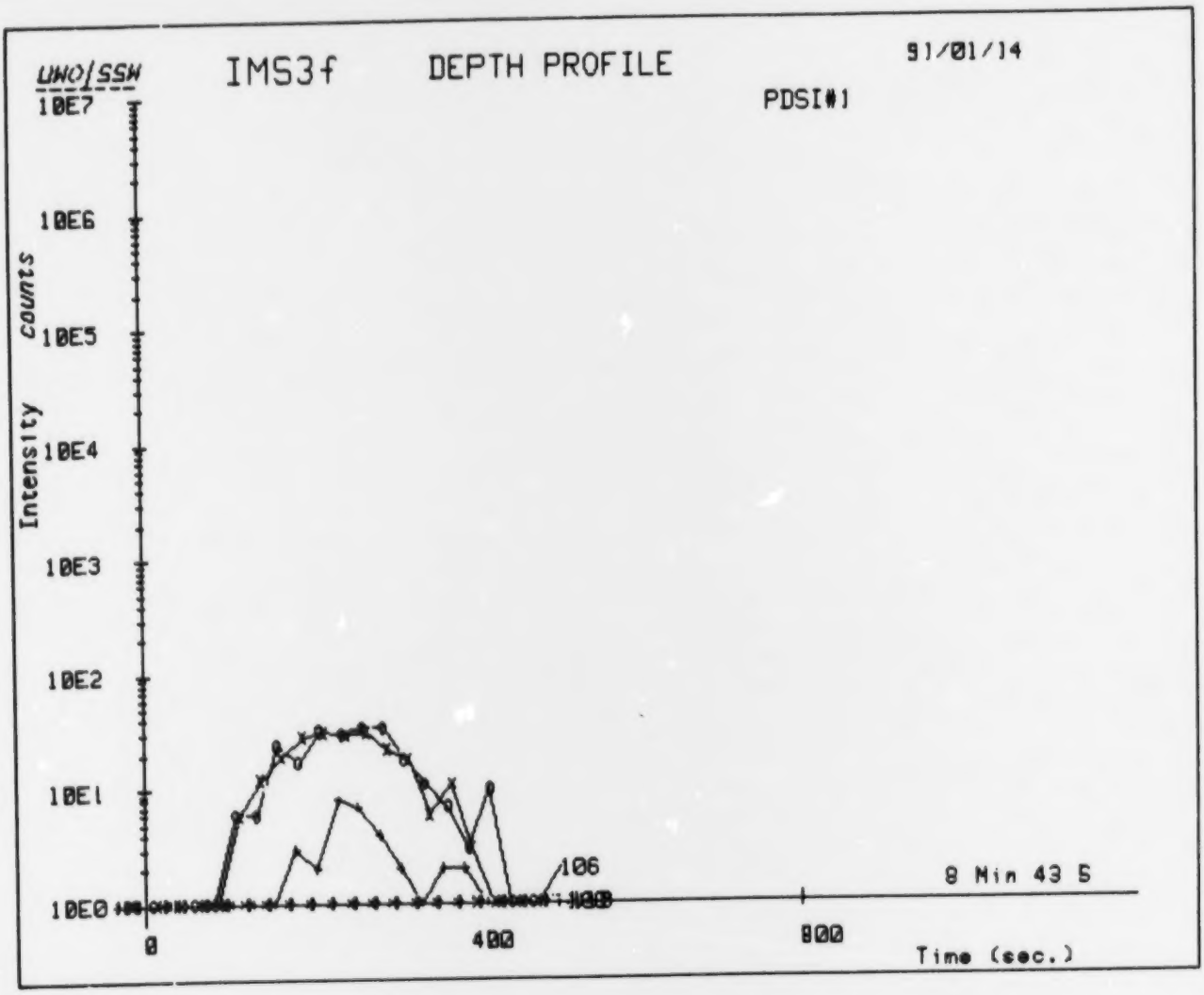
.....TOTAL COUNTS IN PROFILE.....

28 Si	37366794
69 Ga	3509
71 Ga	1

PROFILE TIME 1136.000 SEC.
NUMBER CYCLES 57.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
28	6816364028
69	12802
71	4



SAMPLE:PDSI#1
DATE:91/01/14
PRIMARY IONS : OXYGEN +
SECONDARY IONS : +
DEAD TIME: 500.00E-10 sec.

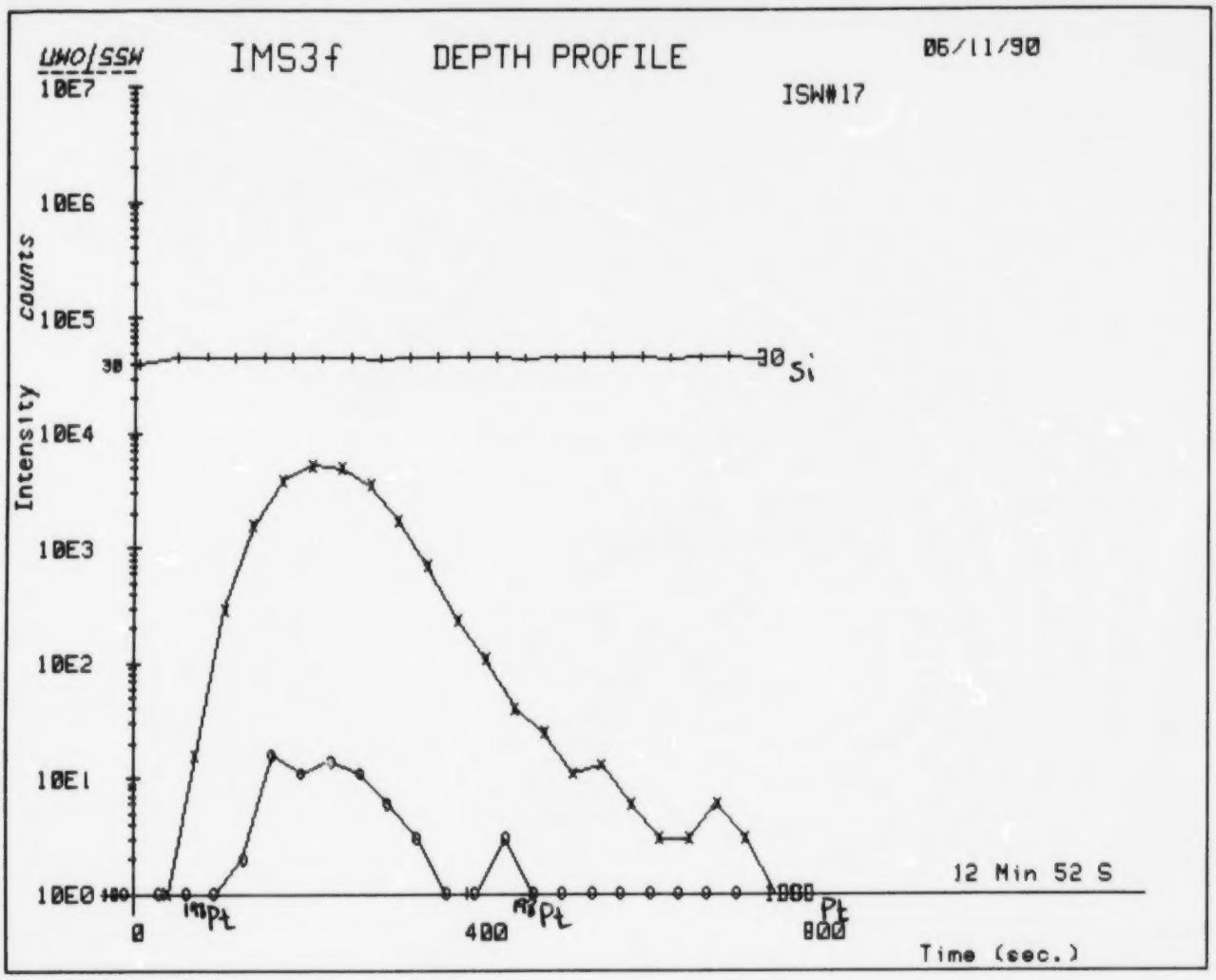
PRIMARY CURRENT : 5058 NANO AMP
HIGH VOLTAGE : 12.4 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

.....TOTAL COUNTS IN PROFILE.....		%
104 Pd	33	6.7
105 Pd	234	47.8
106 Pd	221	45.1
108 Pd	2	0.5
110 Pd	0	

PROFILE TIME 523.000 SEC.
NUMBER CYCLES 20.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
104	263



SAMPLE:ISW#17
DATE:06/11/90
PRIMARY IONS : CS +
SECONDARY IONS : -
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 477 NANO AMP
HIGH VOLTAGE : 9.8 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

.....TOTAL COUNTS IN PROFILE.....

^{30}Si	984362
^{196}Pt	67
^{198}Pt	22169

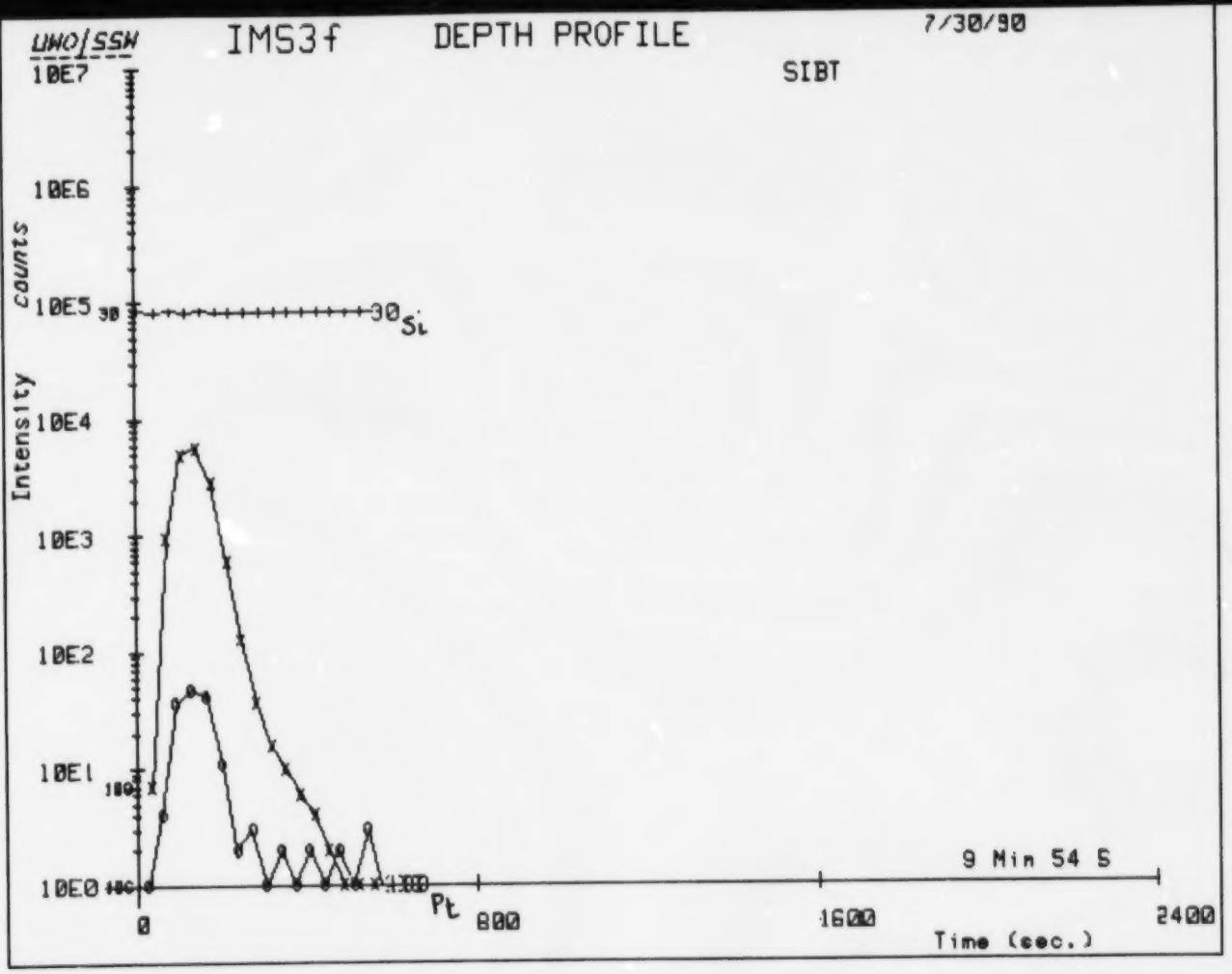
$> 0.0031 \quad \frac{^{196}Pt \times 100}{^{196}Pt + ^{198}Pt} = 0.3\%$

PROFILE TIME 772.000 SEC.
NUMBER CYCLES 22.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
30	316164367
196	215
198	71204

$> .3\%$



SAMPLE:SIBT
DATE:7/30/90
PRIMARY IONS : CS +
SECONDARY IONS : -
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 751 NANO AMP
HIGH VOLTAGE : 9.8 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

Focus

.....TOTAL COUNTS IN PROFILE.....

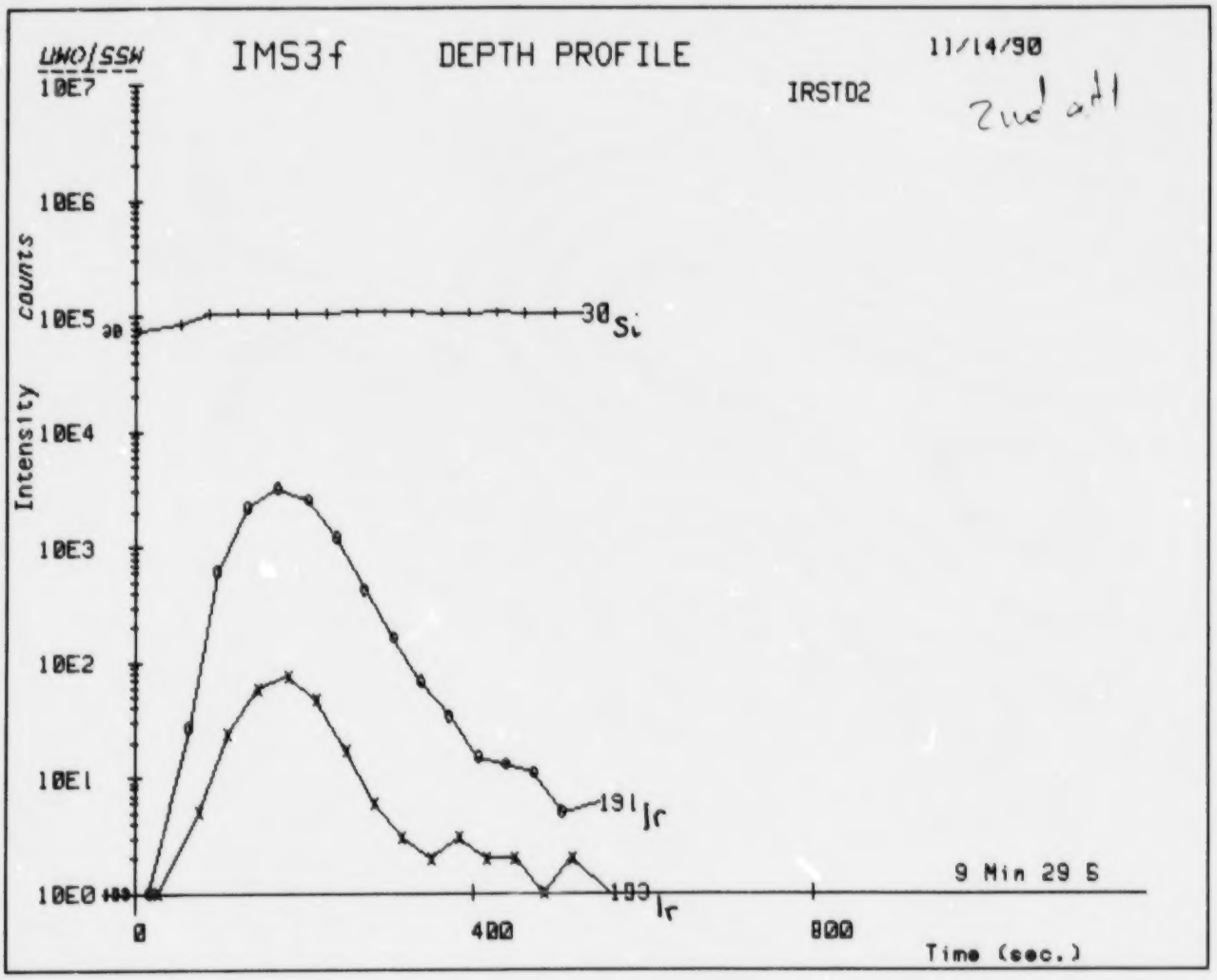
30Si	1399358
196Pt	155
198Pt	15216

$> \frac{196}{196+198} = 1.0\%$

PROFILE TIME 594.000 SEC.
NUMBER CYCLES 17.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
30	447537901
196	496
198	48663



SAMPLE: IRSTD2
DATE: 11/14/90
PRIMARY IONS : CS +
SECONDARY IONS : -
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 738 NANO AMP
HIGH VOLTAGE : 10.2 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

.....TOTAL COUNTS IN PROFILE.....

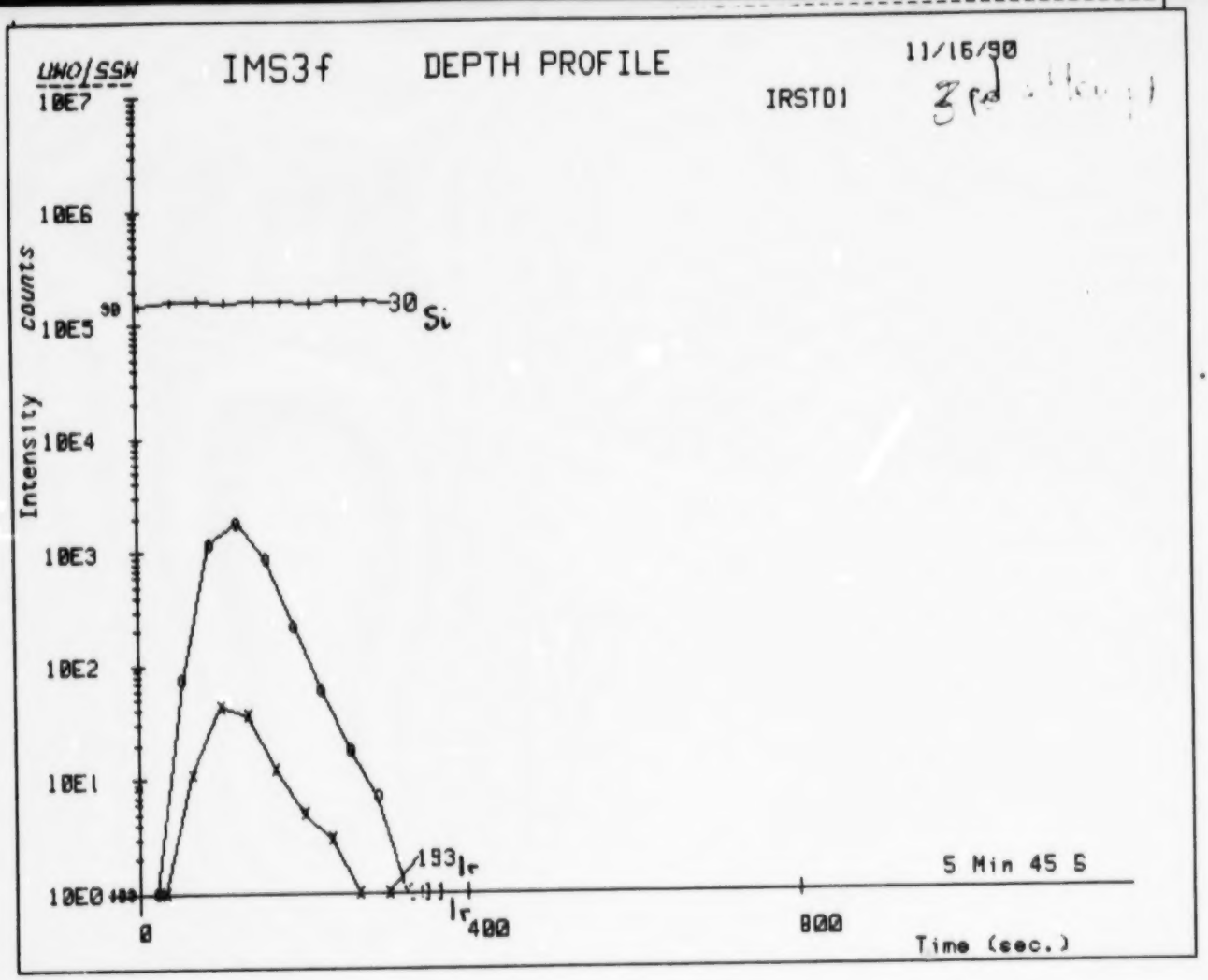
30	1659222
191Ir	10568
193Ir	248

$\frac{^{193}Ir}{^{191}Ir + ^{193}Ir} \times 100 = 2.3\%$

PROFILE TIME	569.000	SEC.
NUMBER CYCLES	16.000	

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
30	540082672
191	34399
193	807



SAMPLE: IRSTD1
DATE: 11/16/90
PRIMARY IONS : CS +
SECONDARY IONS : -
DEAD TIME: 500.00E-10 sec.

PRIMARY CURRENT : 825 NANO AMP
HIGH VOLTAGE : 10.2 KILOVOLTS
RASTERING : 250 MICRONS
TRANSFER OPTICS : 150 MICRONS
FIELD APERTURE : 1 2 3
CONTRAST APERTURE : 4 3 2 1

.....TOTAL COUNTS IN PROFILE.....

30	1569229
191 Ir	4252
193 Ir	113

$\frac{^{193}Ir}{^{191}Ir + ^{193}Ir} = 2.6\%$

PROFILE TIME 345.000 SEC.
NUMBER CYCLES 10.000

TOTAL COUNTS CORRECTED FOR DUTY CYCLE

MASS	TOTAL COUNT
30	495528780
191	13427
193	357